Science and Mathematics Education Centre

Perceptions of the Learning Environment, Attitudes Towards Science, and Understandings of the Nature of Science Among Prospective Elementary Teachers in an Innovative Science Course

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DECLARATION

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgement has been made.

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Date:

ABSTRACT

The major purpose of this study was to evaluate the impact of a science course for prospective elementary teachers on their perceptions of the learning environment, attitudes towards science, and understandings of the nature of science. The sample consisted of 525 female students enrolled in 27 classes of *A Process Approach to Science* (SCED 401) at a large urban university in Southern California. Also comparisons were made between SCED 401 and the students' previous laboratory course with regard to the learning environment and attitudes. Perceptions of the learning environment were measured using scales from the *Science Laboratory Environment Inventory* (Open-Endedness and Material Environment) and the *What Is Happening In this Class?* (Student Cohesiveness, Instructor Support, Cooperation, Investigation). Attitudes towards science were assessed using the Enjoyment of Science Lessons scale from the *Test of Science-Related Attitudes* (TOSRA). Students completed the *Nature of Scientific Knowledge Survey* (NSKS) based on their entire science education experience—not just the one laboratory class which they had taken previously. Comparisons were then made with their understandings after having completed SCED 401. Finally, associations between the learning environment and the student outcomes of attitudes and understandings of the nature of science were explored.

This study embraced the current trend in classroom learning environments research of combining quantitative and qualitative methods. Qualitative components included items from the open-ended questionnaire, *Views of Nature Of Science,* interviews with students, and an analysis of concept maps. The qualitative findings expanded and complemented the quantitative results and, in several cases, supported the construct validity of scales assessing the learning environment and attitudes.

Another purpose of this study was to investigate the effects of using real research data for growth rates of four species of Antarctic seabirds (i.e., implementing an 'intervention') in six classes of SCED 401. The objective of the intervention was to increase the authenticity and quality of an experimental design project. In addition, the wildlife biologist who collected the data guided the students during the project. Although the intervention did not lead to an appreciable improvement in students' perceptions of the learning environment, differences between intervention and nonintervention classes were statistically significant for Enjoyment of Science Lessons from the TOSRA and for Creative from the NSKS (effect sizes were 2.64 and 2.06 standard deviations, respectively).

Results of this study indicated that during a factor analysis, the large majority of learning environment items belonged to their *a priori* scale (43 out of 46 items had factor loadings above 0.40). A valid instrument for use with prospective elementary teachers was produced by combining relevant scales from the *Science Laboratory Environment Inventory* and the *What Is Happening In this Class?* A weaker factor structure was found for the *Nature of Scientific Knowledge Survey.* However, by removing close to half of the 'faulty' items from the NSKS, the internal consistency reliability of scales improved considerably. This study also found large and statistically significant differences between students' previous laboratory class and SCED 401 for all six learning environment scales. The largest difference was found for the level of Open-Endedness (effect size was 6.74 standard deviations). A statistically significant difference also was found for Enjoyment of Science Lessons (effect size was 2.98 standard deviations). Differences were not as dramatic with regard to understandings of the nature of science, although differences for two scales (Creative and Unified) from the NSKS were positive and statistically significant. This study replicated past research by finding statistically significant positive correlations between all six learning environment scales and Enjoyment of Science Lessons. However, by far, Instructor Support had the largest independent association with enjoyment, using both the individual and class mean as the units of analysis. A positive link between a favorable learning environment and the student outcome of understanding nature of science also was found.

This research makes a distinctive contribution to the learning environments field because it is the first study to investigate laboratory classroom environments at the university level with prospective elementary teachers. The study is also the first to build a bridge between the classroom learning environment and the student outcome of understanding the nature of science. The study has implications for undergraduate laboratory course instructors, for science teacher educators who develop and instruct in elementary teacher preparation programs, and for future elementary teachers and the science learning of their future students.

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I was fortunate to receive a lot of help during my study. Priscilla Roy was my research assistant who had the painstaking task of entering scores into a database. My dear mother in British Columbia, Canada, transcribed my interviews and produced over 100 pages of work. Last, but certainly not least, my wonderful husband, Greg, proof-read many of my chapters, helped me with computer and technology problems, and converted my students’ concept maps into an electronic format. Most importantly, he gave me a hug and encouraging words when I needed them the most. This thesis is dedicated to my husband, Greg.

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Chapter 1

INTRODUCTION AND OVERVIEW

1.1 Introduction

Prospective elementary teachers frequently feel an apprehension about teaching science that is rooted in their ‘phobia’ of the subject itself. For many, this fear or dislike of science develops as a result of their own science learning experience being dominated by rote memorization of vocabulary, mathematical abstraction, heavy reliance on textbooks and worksheets, and a dearth of relevant hands-on activities. This all-too-common ‘traditional’ method of science instruction often disillusions and frustrates prospective elementary teachers and, as a result, they tend to avoid science courses during their secondary school and tertiary education, or take only the minimum required number of science courses for their degree. Unfortunately, a fear or dislike of science remains deeply embedded as prospective elementary teachers near the time to step into their own classrooms. Without a positive experience in a college science laboratory course, many future elementary teachers will avoid teaching science to their students altogether, or relegate it to the ‘back burner’—particularly with current pressures in many countries to improve standardized test scores in reading and mathematics at whatever cost. If science *is* taught, many elementary teachers teach it in the same didactic style that they experienced. Unfortunately, the cycle of ineffective science instruction can continue unchecked for generations.

Although many college science courses remain fairly traditional, whether the course is for non-science or science majors, there are exceptions to this generalization. One such exception was the focus for this study. My study assessed the learning environment of a nontraditional college science course that was designed specifically for prospective elementary teachers. It is a course in which basic scientific principles and concepts in the physical, life, and earth sciences are re-emphasized from earlier courses, and which uses a combined laboratory/seminar instructional format that stresses scientific inquiry. In addition, the study assessed attitudes towards science, as well as understandings of the ‘nature of science’, before and after the course.

Chapter 1 provides an overview of my thesis. Section 1.2 gives the reader sufficient background information in order to understand the context of the study. Section 1.3 describes the purpose of and rationale for the study, while Section 1.4 states the five research questions that guided the thesis. Section 1.5 outlines the research design and briefly describes the quantitative and qualitative approaches taken. Section 1.6 describes five reasons why this study is significant. Finally, the last section in this chapter summarizes what can be found in the remaining six chapters of the thesis.

1.2 Context of the Study

The course investigated in this study, called *A Process Approach to Science* (SCED 401), is a component of a Liberal Studies undergraduate degree at California State University, Long Beach in Southern California. Long Beach is located on the coast near the city of Los Angeles and has a diversified population of over 460,000 people. It is the largest and busiest container port on the west coast of North America. Its population is usually included in the census count of 12 million people that live in the greater Los Angeles Metropolitan Area. California State University, Long Beach was established in 1949 to serve the growing population in the region following World War II. At that time, the university primarily focused on teacher education, business education and the liberal arts. Today, California State University, Long Beach is one of 23 campuses in California. In the fall of 2004, it had a total enrollment of about 34,500 students, making it the largest of the state universities. The 23-campus California state university (CSU) system has a student body that reflects California's diversity—students' ethnic backgrounds represent over 150 countries. More than 53% of students are minorities, twice the national average for four-year public universities. About 40% of students come from households where English is not the main language spoken, and about one in five students are the first in their family to attend college. Nearly half of the students come from families making less than US$60,000 per year and, although fees are among the lowest in the US, more than half of CSU students receive financial aid. Only 56% of students are dependent on parents and nearly two in five have dependents themselves. Four out of five students have jobs and 36% work full-time.

Students (prospective elementary teachers) usually take *A Process Approach to Science—SCED 401* in their senior or fourth year, before beginning a teacher preparation program.

Three science laboratory courses (12 units) serve as prerequisites for SCED 401—Physical Science, Geology, and Biology. Data were collected over four semesters when SCED 401 was offered, including the fall 2002, and the spring, summer, and fall semesters of 2003. Seven instructors from the Science Education Department of the College of Natural Sciences and Mathematics taught 27 classes of SCED 401 during this time period, and all followed a similar syllabus. My role during the study was as a participant-observer (Arsenault & Anderson, 1998; Atkinson & Hammersley, 1994). I taught six (22%) of the 27 classes and also I collected and analyzed data that were collected through quantitative and qualitative methods.

Before taking SCED 401, many students struggle through the prerequisite science courses. A small group of students fail to pass one of these courses, and must take it again. Although the prerequisite courses have been undergoing various degrees of revision over the past five years, they are still usually taught in a didactic fashion in large lecture halls, accompanied by 'traditional' laboratory classes with preset or 'cookbook' experiments (emphasizing convergent thinking and a step-by-step scientific method) that often seem disconnected from the material being covered during lectures. Laboratory classes are usually taught by a graduate teaching assistant. These traditional science courses, common throughout many universities in the United States and elsewhere, place a heavy emphasis on content and portray the view that a body of knowledge must be acquired and that there is no time for investigating the processes of science (Tilgner, 1999). As a result, many students beginning SCED 401 fear or do not like science, and they have little confidence in their ability to do well in science or to adequately teach the subject to elementary children.

SCED 401, however, is not a typical laboratory course. It is taught in a hybrid classroom in which an open-ended divergent approach to experimentation is encouraged. Students do not go to a different location for their laboratory investigations, as laboratory classes are integrated into class discussions and mini-lectures. Instructors model hands-on minds-on science teaching strategies where guided-inquiry, risk-taking, creativity, and small-group cooperative learning provide the framework during activities. Typical activities and investigations include Swingers (pendulums), Consumer Product Testing, Mystery Powders, Sinking and Floating, Batteries and Bulbs, Bottle Biology, raising Painted Lady Butterfly larvae and mealworms, pillbug experiments, and planning and conducting an extended experimental design project. A standard textbook is not required for the course, although considerable reading is required. Students must read 25 articles that have been specifically selected for the course, including articles from National Science Teachers Association publications such as the journal *Science and Children.* Students use *The Usborne Book of Science* (Beeson, Chisholm, Kent, Johnson, & Ward, 1993) as a reference, as well as reading *A Beginner's Guide to Scientific Method* by Stephen Carey (2004). Course goals include having students:

(1) like science,
(2) better understand the 'nature of science ' and what actual scientists do, and,
(3) develop their ability to identify, define, and solve problems like scientists do.

The major assignment for SCED 401 involves conducting a large experimental design project. This includes posing a scientific or researchable question, doing background research on the issue/topic in question, planning/selecting a methodology for conducting the research, collecting, analyzing, and interpreting data, forming conclusions, and suggesting implications based on research findings. In past semesters, instructors were disappointed to discover that, by the end of the course, students still had not grasped the nuances of experimental design, and seemed not to understand how actual science is conducted. Most student reports resembled an elementary child's science fair project. As a result of this disappointment, instructors have been trying various approaches to improve the quality and sophistication of this assignment (worth 25 % of students' overall grade).

My approach or intervention was to use a database containing actual research data on Antarctic seabirds called petrels. The purpose of the database was to allow students to manipulate real scientific data so that the sophistication and authenticity of the experimental design project would increase and to increase students' understanding of the nature of science. The data were gleaned from a wildlife/conservation biologist's fieldwork during his two seasons in Antarctica when he collected data on the four species of petrels. The data consisted of chick growth measurements based on four anatomical features, including mass, wing length, tarsus or leg length, and culmen or bill length. The data were organized on several Excel spreadsheets by the wildlife biologist, and placed on my course's web site. The wildlife biologist, Dr Peter Hodum, recently joined our faculty at the university and wished to contribute his knowledge and experience to the Science Education Department. In fact, Dr Hodum has a joint appointment in both the Biological Sciences (75%) and Science Education

(25%) Departments (a hiring trend that is becoming more prevalent across the United States). Although students did not collect their own data as they had done in previous semesters, I predicted that, by providing a real scientist's data to work with, and allowing students to communicate with and ask questions of him, my students would better understand the 'nature of science', experience a positive learning environment, and develop a more positive attitude towards science.

1.3 Purpose of and Rationale for the Study

The purpose of this study was to describe and evaluate the overall impact of an innovative science course for prospective elementary teachers on their perceptions of the learning environment, attitudes towards science, and understandings of the nature of science. I was interested in finding out whether the stated goals of the course were being achieved. I also wanted to identify the benefits of having a science course specifically designed for prospective elementary teachers. To accomplish this, I compared findings from SCED 401 to students' perceptions of the learning environment and attitudes towards science based on their *previous* laboratory course, before beginning SCED 401. It most cases, their previous laboratory course was one of the prerequisite courses mentioned in Section 1.2. What were the similarities and differences between SCED 401 and students' previous laboratory courses? What factors seemed to contribute most to their dislike, fear, and lack of confidence in learning and teaching science? In addition to analyzing and comparing perceptions of the learning environment and attitudes towards science between SCED 401 and previous laboratory courses, I also investigated students' overall understanding of the nature of science prior to beginning SCED 401, based on their *entire* science education experience, not just the one laboratory course, which they had taken previously. Comparisons were then made with SCED 401 results. Could students' understandings of the nature of science be improved with just one course? What aspects of the nature of science, if any, did they better understand after SCED 401?

Another purpose of the study was to evaluate the impact of using the Antarctic seabird database in six classes of SCED 401 that I taught. This was done by comparing my students' learning environment perceptions, attitudes, and nature of science understandings, with the scores of the 21 classes that did not receive the intervention. The purpose of the intervention was to increase the sophistication and authenticity of the experimental design project by providing real research data collected by a wildlife biologist. Although the data were supplied (i.e., it was secondary data) and organized in several Excel spreadsheets, students in the intervention classes were still required to pose a researchable question, choose the appropriate data that would answer their question, reorganize the data into tables, conduct simple statistical calculations, produce and interpret line graphs, make conclusions, write a report, and give an oral presentation on their project to classmates. Students in the nonintervention classes did all of these things as well (to a greater or lesser extent depending on their project), but they were required to design their own study and to collect their own data.

Lastly, I explored associations between the learning environment and the student outcomes of attitudes following considerable prior research (Fraser, 1986b, 1998a, 1998c), and understandings of the nature of science,. In past studies, academic achievement on examinations was the most popular cognitive outcome measure used to investigate associations with the learning environment. My study is unique in that it is the first to explore relationships between the laboratory classroom environment and the nature of science.

1.4 Research Questions

This study was guided by the following five research questions:

1. Is it possible to develop valid and reliable measures of prospective elementary teachers':
    (a) perceptions of the learning environment,
    (b) attitudes towards science, and
    (c) understandings of the nature of science?
2. What is the impact of an innovative science course for prospective elementary teachers on their:
    (a) perceptions of the learning environment,
    (b) attitudes towards science, and
    (c) understandings of the nature of science?

3. Are there differences between students' previous science laboratory course and *A Process Approach to Science* (SCED 401) in terms of :
    (a) perceptions of the learning environment,
    (b) attitudes towards science, and
    (c) understandings of the nature of science?
4. How does using a database containing real research data on Antarctic seabirds for the course's experimental design project affect prospective elementary teachers':
    (a) perceptions of the learning environment,
    (b) attitudes towards science, and
    (c) understandings of the nature of science?
5. Are there associations between learning environment and the student outcomes of:
    (a) attitudes towards science, and
    (b) understandings of the nature of science?

1.5 Research Design

The study employed an evaluative (Guba & Lincoln, 1989) and interpretive design (Erickson, 1998) that centered on "the immediate and local meanings of actions, as defined from the actors' points of view" (p. 119). I was interested in the students' or prospective elementary teachers' perceptions, attitudes, and understandings (i.e. the 'actors'), rather than perspectives by an outside observer or even the instructors. Numerous data sources, involving both quantitative and qualitative methods as recommended by Tobin and Fraser (1998) were used including questionnaires, interviews, and artifacts (i.e., concept maps) from students' examinations.

The questionnaire used in this study contained two distinct sections. The first section used scales from the *Science Laboratory Environment Inventory*—SLEI (Fraser, Giddings, & McRobbie, 1992a, 1992b, 1995; Fraser, McRobbie, & Giddings, 1993), the *What Is Happening In this Class?*—WIHIC (Aldridge, Fraser, & Huang, 1999; Fraser, Fisher, & McRobbie, 1996), and the *Test of Science-Related Attitudes*—TOSRA (Fraser, 1981). This part of the questionnaire assessed the students' perceptions of the learning environment and attitudes towards science, and was administered on the first day of class. Students were instructed to complete this part of the questionnaire with their *previous* science laboratory course in mind. However, a limitation of this retrospective approach can exist when assessing perceptions of the learning environment in a previous course. Although most students reported on a course that they had taken the previous semester, in a small number of cases, some students' previous laboratory course was a course taken one or two years ago. The second section of the questionnaire assessed students' understandings of the nature of science as measured by the *Nature of Scientific Knowledge Survey*—NSKS (Rubba & Anderson, 1978). For the NSKS survey, students were instructed to answer the statements based on their prior *overall* science education experience (not focusing on just one course) and, consequently, the limitation of a retrospective approach did not exist for the NSKS. Near the completion of SCED 401, 15 weeks and close to 60 instructional hours later, students again completed the learning environment/attitude and the nature of science questionnaire assessing SCED 401. Comparisons were then made between perceptions, attitudes, and understandings before and after the course.

In addition to the paper-and-pencil, five-point response scale format of the questionnaire, several open-ended questions were also placed on the Internet. The questions were extracted from the *Views of Nature Of Science*—VNOS (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). Students' responses were compared in a pretest-posttest design. The purpose of the open-ended questions was to provide another perspective to the interpretation of students' understandings of the nature of science. By having both quantitative and qualitative data, a richer and deeper analysis of students' understandings was possible (although a mixed-methods approach has rarely been taken in past nature of science research).

In order to triangulate findings from the quantitative data derived from the questionnaire, interviews were conducted with 35 students in two of the intervention classes during the fall of 2003. Semi-structured questions were asked that addressed the learning environment, attitudes towards science, and understandings of the nature of science. Interviews were audiotaped, transcribed, reread numerous times and, through the process of analytic induction (Erickson, 1998; Glaser & Strauss, 1967; Lindesmith, 1947) several themes (Erickson, 1998) were identified that summarized the main findings.

Lastly, samples of student work during an examination (i.e., concept maps) were collected from the intervention classes. The purpose of the concept map question was to assess the impact, in a graphical form, of providing students with real research data on Antarctic seabirds for their experimental design project and to see how they synthesized this information with their emerging understandings of the nature of science.

Concept maps have many practical applications in teaching, learning, and research. For example, Figure 1.1 provides a graphical representation of my overall study. The concept map in Figure 1.1 is an alternative method for describing the details and connections in this large, mixed-methods study. Further details of my research design, described in a narrative form, can be found in Chapter 3—Research Methods.

1.6 Significance of Study

This study is significant for five reasons. First, although research has been conducted in the learning environments field for over 35 years, little research involving teacher education programs has adapted a learning environments framework. My study included all female prospective elementary teachers (N=525) who took the required science capstone course, SCED 401, during fall 2002 and spring, summer and fall 2003 semesters. Each class only had one or two male students which is typical for the SCED 401 course. Because the majority of prospective elementary teachers in my university and throughout the California State University system are typically female, I controlled the variable of gender, and only included the females' responses in my data analysis. The learning environment questionnaire modified for use with this sample can be used with confidence in future studies involving female prospective or preservice teachers in a laboratory class.

Second, findings from my study could have implications on both the future teaching practice of elementary teachers and the learning of their future students. Elementary teachers must have a broad knowledge base in several rigorous academic areas including science, language arts, mathematics, and social studies. Throughout many countries, school and district administrators and politicians have recently been overly focused on improving standardized test scores in mathematics and reading. If beginning elementary teachers dislike science, are not confident in their ability to teach science, and do not have positive experiences during their teacher education program in college, all coupled with pressures to improve mathematics and reading test scores, science is likely to be the first subject dropped from their students' instruction. I believe that, with a positive experience in an undergraduate

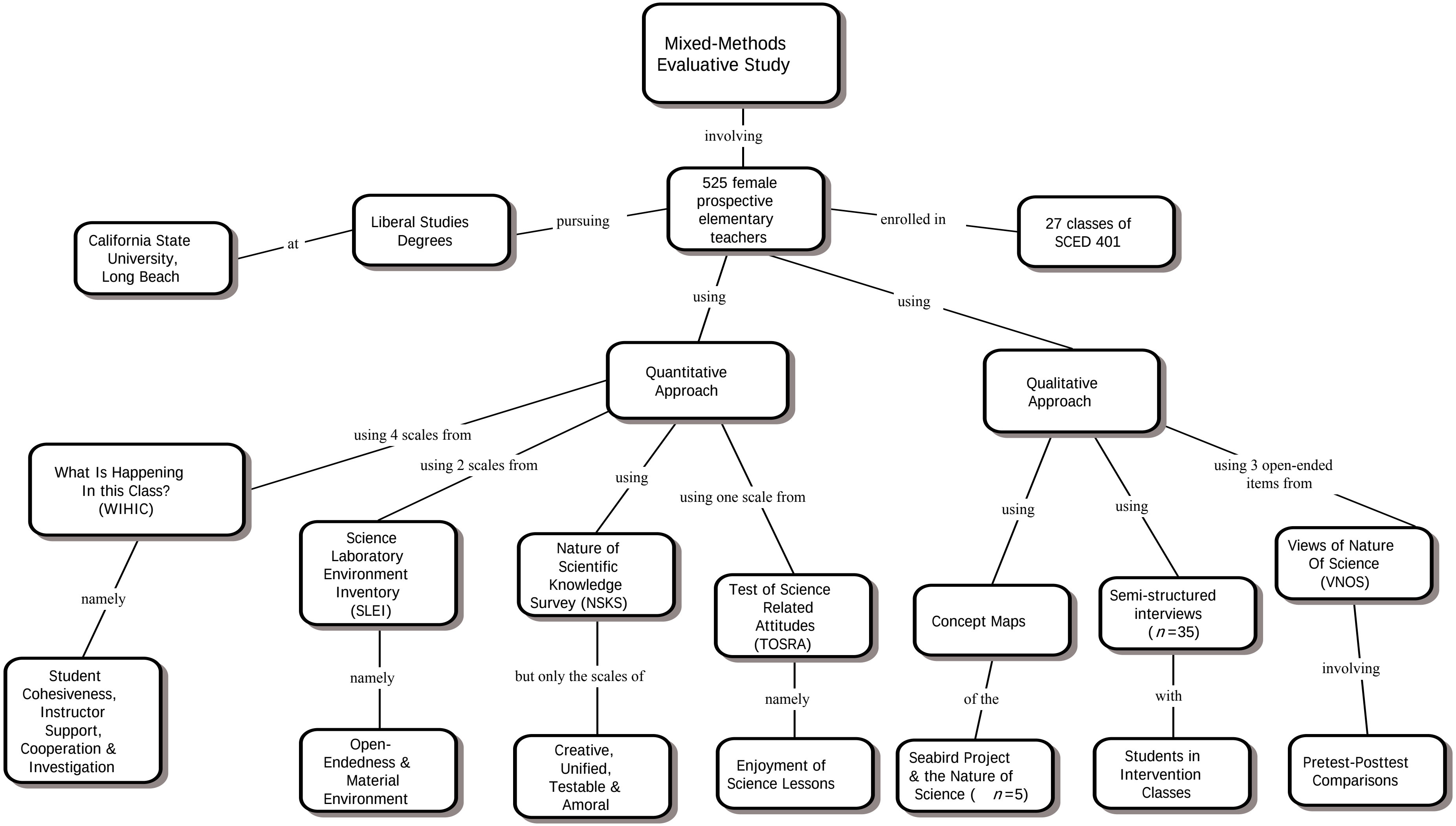

Figure 1.1. Concept map showing overview of study

science laboratory class, future elementary teachers are more likely to teach science to their own students. If their students receive science instruction in elementary school, children will be more likely to continue liking science, develop scientific thinking skills, be more prepared for secondary school science, and continue taking science courses. SCED 401 can be a model for other colleges and universities with elementary teacher education programs that usually do not have such a course.

Third, this study is significant because it builds upon a 2000 study that also focused on SCED 401. Bianchini and Colburn's (2000) research investigated the implicit use of inquiry to teach the nature of science in SCED 401. My study extends Bianchini and Colburn's work by exploring whether or not there are associations between the learning environment and the nature of science. Previously, only one study has identified an association between understanding the nature of science and the learning environment (Lederman & Druger, 1985).

Fourth, although SCED 401 is considered an innovative science course, any course can be improved, particularly when one of the course's more challenging goals is to have students better understand the nature of science and what actual scientists do. Teacher education programs throughout the US, and in many countries, vary a great deal, but most incorporate the nature of science during a science methods course (if they cover this topic at all). SCED 401 is unusual in that it addresses the nature of science in a science content course for teachers and, in the intervention classes, allows students to use real scientific data for an experimental design project. This study is significant because it provides data on the merits of a nontraditional laboratory science course specifically designed for prospective elementary teachers and on the effects of an intervention in which a guided authentic inquiry experience is integral to the course.

Lastly, this study is significant in that it used multiple research approaches in order to produce an in-depth, rich, and contextual understanding of prospective elementary teachers' experiences during SCED 401. This study builds upon previous learning environment studies that have also used the idea of *grain sizes* (the use of different-sized samples for different research questions varying in intensiveness and extensiveness) when combining qualitative and quantitative paradigms (Aldridge et al., 1999; Creswell, 1994; Fraser, 1999; Fraser & Tobin, 1991; Tobin & Fraser, 1998).

1.7 Overview of the Thesis

The remainder of my thesis, following this chapter, includes six additional chapters. Chapter 2, entitled Classroom Learning Environments: Review of Related Literature, provides an overview of the major area of focus in my study. There are five major sections in chapter 2. One section describes the term 'learning environments' and provides an overview of the history and development of the classroom learning environments field. The section also discusses several important issues (e.g., use of personal or class form, unit of analysis) that must be addressed during any learning environments research. A researcher can choose from a large selection of 'types' or approaches to learning environments research and these are described as well. Another section describes seven of nine historically-important questionnaires that have been designed over the past 35 years, and reviews noteworthy studies associated with each instrument. A review of the development, validation and use of the *Science Laboratory Environment Inventory—SLEI* comprises another section in chapter 2. Because two scales were used from the SLEI in my study, considerable detail on past research utilizing the SLEI is provided. I also used four scales from the *What Is Happening In this Class?—WIHIC* and another section in the chapter reviews the development, validation and use of this instrument. The last major section reviews the development and validation of the *Test Of Science-Related Attitudes—TOSRA* because I also used one scale from this instrument for my study. The student outcome of attitudes towards science is frequently studied alongside perceptions of the classroom learning environment. In my study, I wanted to know how the attitudes of prospective elementary teachers in the course, SCED 401, are associated with perceptions of the laboratory classroom learning environment.

Chapter 3, entitled The Nature of Science: Review of Related Literature, covers a large research field similar to the learning environments field. Because the second half of the study's questionnaire included the *Nature of Scientific Knowledge Survey—NSKS* (Rubba & Anderson, 1978), it was important to review past research that used the NSKS and to review studies in general that have assessed elementary teachers' understandings of the nature of science. As mentioned earlier, improving students' understandings of the nature of science is one of the goals of SCED 401. In addition to students completing the convergent, paper-and-pencil survey, they also answered several items from an open-ended response questionnaire called *Views of Nature Of Science—VNOS* (Lederman et al., 2002) that were posted on the course's website. The VNOS is a contempory instrument that is popular among nature of science researchers who use a qualitative method. It was chosen for this study in order to add depth and richness to the quantitative findings derived from the NSKS. Associations between the laboratory classroom environment and the student outcome of understanding the nature of science also were explored in this study and, therefore, it was appropriate to include a review of literature about the field of nature of science as well as about the field of classroom environments. Chapter 3 contains six sections. The sections define and explain what is meant by the term ‘nature of science’, provide an overview of the nature of science as an educational goal, describe the development and validation of the NSKS and VNOS, discuss issues and trends related to teaching and learning about the nature of science, and review specific studies that investigated elementary teachers’ conceptions of the nature of science, first between 1950 and 1990, and then between 1991 and the present.

Chapter 4, entitled Research Methods, contains nine major sections. The first section describes the sample for this study (525 female prospective elementary teachers), the second section explains my role in the study as a participant-observer, and the third section discusses the rationale for combining qualitative and quantitative approaches. Specific details on the structure of the modified science learning environment survey, the attitude scale, the *Nature of Scientific Knowledge Survey,* and on the items from *Views of Nature Of Science* are all discussed in the fourth section called Questionnaires. A fifth major section entitled Interviews With Students in the Intervention Classes of SCED 401 describes how I conducted semi-structured interviews with 35 students during the fall semester of 2003. A sixth section describes concept maps that were produced during an examination in one of the intervention classes. The concept maps were analyzed in order to assess the impact of providing students real scientific data on Antarctic seabirds and chick growth rates for their experimental design project. The purpose of the examination question was to evaluate the extent to which students could show how the Seabird Project helped them to understand the nature of science. Another section entitled Methods of Data Analysis describes how the science learning environment and *Nature of Scientific Knowledge Survey* scales were validated and, explains how differences between previous laboratory courses and SCED 401 and differences between the intervention and nonintervention classes were determined with regard to the learning environment, attitudes towards science, and understandings of the nature of science. Additional subsections in Methods of Data Analysis deal with how associations between the learning environment and the student outcomes of attitudes and the nature of science were explored, how the online responses for the nature of science questions were analyzed, and how the information from the interviews and concept maps were analyzed. Chapter 4 concludes by discussing some limitations associated with the methods used.

Chapter 5–Quantitative Results is divided into eight sections. Two sections describe the factor analysis that was conducted on the modified science learning environment survey and the *Nature of Scientific Knowledge Survey.* Another section describes the internal consistency reliability, discriminant validity, and ability to differentiate between classrooms for the learning environment scales. Internal consistency reliability also are reported for the Enjoyment of Science Lessons scale and for the NSKS. In addition, discriminant validity is reported for the NSKS. Results of the paired-samples *t*-tests exploring differences between previous laboratory courses (usually one of the prerequisite courses—Physical Science, Biology or Geology) and SCED 401 scores are provided for the learning environment and attitude scales. Differences are reported between students' understandings of the nature of science before SCED 401 began (pretest) and their understandings of the nature of science after SCED 401 (posttest). Differences between the intervention classes that used the Antarctic seabird data and those classes that did not—the nonintervention classes—were analyzed as well using scales from the modified science learning environment questionnaire, the *Test of Science-Related Attitudes*, and from the *Nature of Scientific Knowledge Survey.* The last section in Chapter 5 reports on associations between the learning environment and the student outcomes of attitudes and understandings of the nature of science.

Chapter 6, Qualitative Results, discusses the data generated through qualitative methods. This study embraced the recent trend in learning environments research of using a mixed-methods approach. Combining methods in a single study achieves complementarity and reveals the overlapping and different facets of phenomena—an idea analogous to peeling away the layers of an onion (Greene, Caracelli, & Graham, 1989). The results are discussed in three major sections. One section describes the content analyses of student responses to the open-ended items from the *Views of Nature of Science.* A comparison of students' pretest and posttest responses are summarized in analytic charts that help to shed light on differences in understandings of the nature of science before and after SCED 401. Another section describes *themes* (Anderson, 1998; Creswell, 1994; Seidman, 1991) that were identified from the analytical induction process of the student interviews. Five themes emerged that encapsulated the 35 prospective elementary teachers' responses. Lastly, a section describes information gleaned from the concept map analysis. The concept maps illustrate through a graphical representation how five prospective elementary teachers in the intervention classes perceived the influence of the Seabird Project in shaping their understanding (or lack of understanding) of the nature of science.

Chapter 7, entitled Discussion and Conclusions, provides a summary of the thesis. This is further broken down into a summary of the introductory chapter, the two chapters that reviewed literature relating to classroom learning environments and the nature of science, the research methods chapter, the quantitative results chapter, and the qualitative results chapter. An additional section discusses the distinctive contributions, significance and implications of my study. Another section mentions constraints and limitations that are inherent in any study. Six recommendations for further research are provided near the end of the chapter. Finally, the last section in Chapter 6 provides an overall chapter summary and concluding remarks.

Chapter 2

CLASSROOM LEARNING ENVIRONMENTS: REVIEW OF RELATED LITERATURE

2.1 Introduction and Overview

This chapter reviews literature related to the field of classroom learning environments, the primary research area covered in my study. Section 2.2—Background to the Learning Environments Field, describes the term 'learning environments' and provides an overview of the history and development of the classroom learning environments field, as well as discussing salient issues (e.g., private and consensual beta press, unit of analysis) and types of research. Section 2.3—Instruments Assessing the Learning Environment, describes seven of nine historically-important questionnaires that have been designed over the past 35 years, and reviews noteworthy studies associated with each instrument. The development and validation of these instruments is a distinctive feature of the field of classroom learning environments.

Section 2.4—Development, Validation and Use of the SLEI, describes the conceptualization, development and application of the *Science Laboratory Environment Inventory*—SLEI (Fraser et al., 1992a, 1992b, 1993, 1995). Because two scales were used from the SLEI in my study, considerable detail on past research utilizing the SLEI is provided in four subsections that review cross-national studies involving six countries, cross-validation studies in Australia, and laboratory learning environments in Asia and Israel. Because I also used four scales from *What Is Happening In this Class?*—WIHIC (Fraser et al., 1996), Section 2.5—Development, Validation and Use of WIHIC, provides important information on past research in which the WIHIC was used. Like the previous section, Section 2.5 is divided into subsections in order to organize the many important studies involving the WIHIC. The subsections review studies that were conducted at the university level, that made cross-national comparisons in science and mathematics classrooms, that involved secondary science students in a single country, that assessed technology-rich learning environments and, lastly, that were conducted in South Africa where interest in learning environment research has been growing.

The student outcome of attitudes towards science is frequently studied alongside psychosocial perceptions of the classroom learning environment. In my study, I also wanted to know how the attitudes of prospective elementary teachers enrolled in the course, *A Process Approach to Science—SCED 401*, are associated with perceptions of the laboratory classroom learning environment. In order to investigate this question, one scale (eight items) from the *Test of Science-Related Attitudes* (TOSRA) (Fraser, 1981) was used. Therefore, Section 2.6—Attitudes Towards Science and Their Link with the Learning Environment, reviews the development and validation of the TOSRA, studies investigating associations between the learning environment and attitudes, and additional studies specifically focusing on attitudes towards science among elementary teachers.

Lastly, Section 2.7 provides a summary of the chapter.

2.2 Background to the Learning Environments Field

The learning environment of a classroom can be described as the overall climate, culture, ambience, or atmosphere in which learning takes place. The learning environment describes the intangible aspects of a classroom that give it a particular feel or tone. It can be sensed when a stranger spends only a few minutes in a room. For example, the atmosphere in a classroom can be charged with dozens of excited voices, anticipation, and a spirit of discovery. Or it can be cloaked with suppression, uncomfortable silence, and a humdrum feeling.

In schools, we often only assess academic achievement, the usual yardstick for measuring teaching and learning effectiveness, but this can dehumanize the educational process. Reporting achievement, along with a description of the learning environment as assessed by the questionnaires discussed in the following sections, can give a more complete and accurate picture of classroom learning environments. Considering that university students spend approximately 20,000 hours in classrooms by the end of their tertiary education (Fraser, 2001), it seems not only logical but essential for researchers and educators to obtain information from students about what they think of their learning environments.

The history of learning environments research has its roots in the social sciences. Lewin (1936) and Murray (1938) were the pioneer psychologists who first analyzed psychosocial environments. Lewin emphasized that both the environment and its effects on the individual determine human behavior. He represented his ideas through his well-known formula, $B=f(P,E)$ in which Behavior (B) is a function of both the Person (P) and the Environment (E). Lewin also distinguished between 'beta press'—a description of the environment as perceived by the people themselves in the environment, which he felt was a function of the interaction between a person and his or her environment, and 'alpha press'—a description of the environment as observed by a detached observer, which is a common approach used in psychology and educational research. Lewin and Murray pointed out, however, that there are many advantages in considering 'beta press' because an outside observer can miss important and relevant events and interactions. (This philosophy lies at the core of all classroom learning environment questionnaires.) Murray applied Lewin's concept of alpha and beta press to his 'needs-press model' in which 'needs' refer to an individual's motivation to achieve goals, while 'press' describes how the environment either helps or hinders a person to meet their goals or needs.

The first learning environment questionnaires for use in educational settings were developed in the late 1960s and early 1970s in the United States. The first instrument was called the *Learning Environment Inventory* (LEI), developed by Walberg and Anderson (1968) during the evaluation of the well-known Harvard Project Physics program. The LEI assessed students' perceptions of their secondary physics classrooms in terms of the whole-class environment. At about the same time, Rudolf Moos, working independently at Stanford University, began studying environments as diverse as psychiatric hospitals, university residences, conventional work sites, and correctional institutions. Moos had responded to the increased interest in a relatively new field of psychology called 'human (or social) ecology', in which one investigates how people grow and adapt to their various environments. Of practical concern was the question: "How can an environment be created that maximizes human functioning and competency?" (Moos, 1979). Moos' studies eventually took him to educational settings such as schools, and he subsequently developed the *Classroom Environment Scale* (CES; Moos, 1974, 1979; Moos & Trickett, 1987) which asked students for their perceptions of the learning environment of the class as a whole.

All of the early instruments assessed students' perceptions of the classroom environment as a whole or as a single entity. Stern, Stein, and Bloom (1956) extended Murray's notion of beta press into 'private beta' press (an individual's view of their environment) and 'consensual' beta press (the shared view of a group as a whole), but the distinction between private and consensual press did not take root until the development of the *Science Laboratory Environment Inventory*. Which level of analysis to use in a study is a crucial consideration, however, because private and consensual beta press could, and often do, differ from each other. Fraser (1998a) explains that the choice of unit of analysis is important:

> Measures having the same operational definition can have different substantive interpretations with different levels of aggregation; relationships obtained using one unit of analysis could differ in magnitude and even in sign from relationships obtained using another unit; the use of certain units of analysis (e.g., individuals when classes are the primary sampling units) violates the requirement of independence of observations and calls into question the results of any statistical significance tests because an unjustifiably small estimate of the sampling error is used; and the use of different units of analysis involves the testing of conceptually different hypotheses. (p. 530)

The CES, LEI and all learning environment instruments that followed were modeled on Moos' three basic categories for describing human environments. These categories were developed from his earlier 'social ecological' perspective. The categories are based on 'relationship', 'personal development', and 'system maintenance and change' dimensions. These dimensions are defined below:

> *Relationship* dimensions identify the nature and intensity of personal relationships within the environment and assess the extent to which people are involved in the environment and support and help each other, *Personal Development* dimensions assess basic directions along which personal growth and self-enhancement tend to occur, and *System Maintenance and System Change* dimensions involve the extent to which the environment is orderly, clear in expectations, maintains control and is responsive to change. (Fraser, 1998a, p. 530)

Table 2.1 in Section 2.3 shows how each of nine historically-important classroom learning environment instruments have scales that fall into one of Moos' dimensions. The table also indicates that the third instrument to follow the LEI and CES was a questionnaire called *My Class Inventory* (MCI), a simplified form of the LEI developed for use among elementary children (Fisher & Fraser, 1981). This third instrument, designed for use in 'teacher-centered' classrooms similar to the LEI and CES, helped to establish the roots of the learning environments field with studies throughout the 1980s, 1990s, and even into the 21st century

(Fraser, 1986b; Fraser & Fisher, 1986; Fraser & O'Brien, 1985; Goh, Young, & Fraser, 1995; Majeed, Fraser, & Aldridge, 2002). The *Individualized Classroom Environment Questionnaire* (ICEQ; Fraser, 1990) that followed the LEI, CES, and the MCI, was the first instrument devised with 'student-centered' classrooms in mind. Section 2.3 provides an overview of the LEI, CES, MCI, ICEQ, and three other questionnaires that have served as the backbone to learning environments research over the past 35 years.

The pioneering work of Walberg and Moos not only led to the creation of many invaluable questionnaires, but it also provided the basis for the creation of several influential books, book chapters, and journal articles that laid the groundwork for the growing learning environments field (Fraser, 1986b; Fraser & Walberg, 1981, 1991; Moos, 1979, 1991; Walberg, 1979; 1981, 1986; Walberg, Fraser, & Welch, 1986). The instruments that were developed and validated after the LEI and the CES, their availability and ease of use, is a hallmark of learning environments research today (Fraser, 1998a, 1998b). Through a review of nine contemporary instruments in Sections 2.3—2.5, along with a discussion of noteworthy studies, the vast scope of classroom learning environments research can be appreciated. Moos' influence over 30 years ago can still be seen in the modification of existing instruments, and in the creation of new instruments that reflect current educational trends such as a constructivist pedagogy (e.g., *Constructivist Learning Environment Survey—CLES* and the new *University Social Constructivist Learning Environment Survey—USCLES* that is being developed by faculty at Curtin University of Technology), the use of laptop computers in classrooms (Raaflaub & Fraser, 2003), Internet and technology-enriched classrooms (Aldridge, Fraser, Fisher, & Wood, 2002; Van den Berg, 2004; Zandvliet & Fraser, 2004), distance education learning environments (Walker & Fraser, 2004), and the development of online surveys (Trinidad, Fraser, & Aldridge, 2004).

Another impressive feature of the learning environments field is the international flavor of research in which researchers from four continents and a dozen different countries have investigated tens of thousands of classroom learning environments. From its genesis in the United States, learning environments research spread first to Australia with *My Class Inventory* (MCI; Fisher & Fraser, 1981) and the *Individualized Classroom Environment Questionnaire* (ICEQ; Fraser, 1990), then to The Netherlands with the development of the *Questionnaire on Teacher Interaction* (QTI; Wubbels & Levy, 1993), to Southeast Asian countries such as India (Walberg, Singh, & Rasher, 1977), Japan (Hirata, Ishikawa, & Fraser, 2004; Hirata & Sako, 1998), Singapore (Chua, Wong, & Chen, 2001; Fisher, Goh, Wong, & Rickards, 1997; Fraser & Chionh, 2000; Goh & Fraser, 1996, 1998, 2000; Goh et al., 1995; Quek, Fraser, & Wong, 2001; Wong, Young, & Fraser, 1997), Indonesia (Adolphe, Fraser, & Aldridge, 2003; Margianti, 2002; Paige, 1979; Soerjaningsih, Fraser, & Aldridge, 2001), Taiwan (Aldridge & Fraser, 2000; Aldridge et al., 1999), Korea (Kim & Kim, 1995, 1996; Kim, Fisher, & Fraser, 1999, 2000; Kim & Lee, 1997; Lee & Fraser, 2001), Hong Kong (Cheung, 1993; Wong, 1993, 1996) and Brunei Darussalam (Asghar & Fraser, 1995; Khine & Fisher, 2002; Majeed et al., 2002; Riah & Fraser, 1998; Scott & Fisher, 2001, 2004), South Pacific Islands (Giddings & Waldrip, 1996), Canada (Dorman, 2003; Fraser & Griffiths, 1992; Raaflaub & Fraser, 2003; Zandvliet, 2000; Zandvliet & Fraser, 2004), Israel (Hofstein, Cohen, & Lazarowitz, 1996; Hofstein, Levy Nahum, & Shore, 2001) and, recently, research has emerged from South Africa (Fisher & Fraser, 2003; Ntuli, Aldridge, & Fraser, 2003; Seopa, Laugksch, Aldridge, & Fraser, 2003).

After its start in the United States, the focus of learning environments research became firmly established in Australia in the early 1980s and has remained in that country to the present day. Australia's Asian neighbors to the north, however, have been quite prolific and many studies with large sample sizes have appeared. In 2002, an edited book called *Studies in Educational Learning Environments: An International Perspective* (Goh & Khine, 2002) was published that reviewed the distinctive contribution of Asian researchers. Researchers have cross-validated several questionnaires such as the *Questionnaire on Teacher Interaction, Science Laboratory Environment Inventory, Constructivist Learning Environment Survey,* and *What Is Happening In this Class?* in English-speaking countries (Singapore and Brunei), but also have completed the laborious task of translating, back-translating and validating these instruments in the Chinese, Indonesian, Korean, and Malay languages (Fraser, 2003).

Cross-national studies that began with the development and validation of the *Science Laboratory Environment Inventory* in six countries, including the USA, Canada, England, Israel, Australia, and Nigeria, continue to expand and offer much promise for generating new insights into the cultural similarities and differences between countries, as well as establishing unique collaborations between researchers (Adolphe et al., 2003; Aldridge & Fraser, 2000; Aldridge et al., 1999; Giddings & Waldrip, 1996; Zandvliet & Fraser, 2004). Many of these studies are reviewed in Sections 2.4 and 2.5 in which I discuss the development, validation and use of the *Science Laboratory Environment Inventory* and *What Is Happening In this Class?*

Cross-national studies are one type of learning environments research. Fraser (1998c) identifies 11 other types of research: (1) associations between student outcomes (e.g., cognitive achievement and attitudes) and learning environment, (2) evaluation of educational innovations (e.g., in the present study), (3) differences between students' and teachers' perceptions of the same classrooms, (4) whether students achieve better when in their preferred environments (also called person-environment fit studies), (5) teachers' practical attempts to improve their classroom climates (also called action research), (6) combining qualitative and quantitative methods, (7) school psychology, (8) links between educational environments such as the classroom, home and parents' work locations, (9) transition from primary to secondary education, (10) teacher education, and (11) teacher assessment. The most frequent focus in past studies has been associations between students' cognitive and affective learning outcomes and their perceptions of the classroom environment. In a meta-analysis involving an amazing 734 correlations from 12 studies involving 823 classes, eight subject areas, 17,805 students and four nations (Haertel, Walberg, & Haertel, 1981), learning posttest scores and regression-adjusted gains were consistently and strongly associated with cognitive and affective learning outcomes. Another tabulation of 40 more recent studies (Fraser, 1994) shows that associations between outcome measures and classroom environment perceptions have been replicated for a variety of instruments and a variety of samples ranging across numerous countries and grade levels. Examples of most of these types of research are provided in Sections 2.3—2.5 in which I discuss individual instruments.

Whereas early research on classroom learning environments used predominantly quantitative methods, combining quantitative and qualitative methods is a distinctive thrust of current research (Tobin & Fraser, 1998). In particular, researchers have complemented their large-scale questionnaire surveys with focused classroom observations and with interviews with a small sample of students in order to uncover rich, contextual understandings of learning environments. This in turn has led to insightful qualitative writing in the form of narrative stories (Carter, 1993; Clandinin & Connelly, 1994; Denzin & Lincoln, 1994) and interpretive commentaries (Geelan, 1997). By drawing on a range of paradigms, making use of triangulation, and embracing the idea of 'grain sizes' (the use of different-sized samples for different research questions varying in extensiveness and intensiveness) (Fraser, 1999), the field of learning environments research is in a strong position to meet the demands of future educational questions.

2.3 Instruments Assessing the Classroom Learning Environment

This section describes seven of nine historically-important and contemporary questionnaires that have been used to assess the psychosocial perceptions of classroom learning environments among elementary, secondary and tertiary students. Notable studies that utilized each of the questionnaires also are reviewed. The *Science Laboratory Environment Inventory* and *What Is Happening In this Class?* are reviewed in greater detail in Sections 2.4 and 2.5 because they were used as a source of scales for my study. Table 2.1 provides an overview of the questionnaires and indicates the name of the instrument, its developers, intended level of usage, number of items per scale, the name of each scale, and how each scale aligns with Moos' three dimensions.

2.3.1 Early Classroom Learning Environment Questionnaires—LEI, CES and MCI

2.3.1.1 Learning Environment Inventory (LEI)

As mentioned in Section 2.2, the *Learning Environment Inventory* (Walberg & Anderson, 1968) was the first questionnaire developed. Initially, its main purpose was to evaluate the Harvard Project Physics program, an innovative hands-on inquiry-based curriculum that was motivated by Russia's launch of Sputnik into space, but it was subsequently used in many studies in which the classroom learning environment served as the dependent or criterion variable and independent variables included such things as sex of the science teacher (Lawrenz & Welch, 1983), teacher personality (Walberg, 1968), class size (Anderson & Walberg, 1972), wait time during questioning in science lessons (Cohen, 1978), and new curricular initiatives (Fraser, 1986b, p. 121). The LEI also was used in studies of associations between student outcomes and classroom environment, thus serving as the independent or predictor variable. Outcome measures included academic achievement, attitudes, understanding of the nature of science, and science process skills (Fraser, 1986b, p. 89).

Table 2.1

Overview of Scales Contained in Nine Learning Environment Instruments (LEI, CES, ICEQ, MCI, CUCEI, QTI, SLEI, CLES, and WIHIC)

Instrument	**References**	**Level of Usage**	**Items per scale**	**Scales classified according to Moos' scheme**		
				Relationship dimensions	***Personal development dimensions***	***System maintenance and change dimensions***
Learning Environment Inventory (LEI)	Fraser, Anderson, & Walberg, 1982; Walberg & Anderson, 1968	Secondary	7	Cohesiveness Friction Favoritism Cliqueness Satisfaction Apathy	Speed Difficulty Competiveness	Diversity Formality Material environment Goal direction Disorganization Democracy
Classroom Environment Scale (CES)	Moos, 1974, 1979; Moos & Trickett, 1987	Secondary	10	Involvement Affiliation Teacher support	Task orientation Competition	Order and organization Rule clarity Teacher control Innovation
Individualized Classroom Environment Questionnaire (ICEQ)	Fraser, 1990; Rentoul & Fraser, 1979	Secondary	10	Personalization Participation	Independence Investigation	Differentiation
My Class Inventory (MCI)	Fisher & Fraser, 1981; Fraser, Anderson, & Walberg, 1982; Fraser & O'Brien, 1985	Elementary	6-9	Cohesiveness Friction Satisfaction	Difficulty Competitiveness	
College & University Classroom Environment Inventory (CUCEI)	Fraser & Treagust, 1986; Fraser, Treagust, & Dennis, 1986	Higher Education	7	Personalization Involvement Student cohesiveness Satisfaction	Task orientation	Innovation Individualization
Questionnaire on Teacher Interaction (QTI)	Créton, Hermans, & Wubbels, 1990; Wubbels, Brekelmans & Hooymayers, 1991; Wubbels & Levy, 1993	Primary/Secondary	8-10	Helpful/friendly Understanding Dissatisfied Admonishing		Leadership Student responsibility and freedom Uncertain Strict
Science Laboratory Environment Inventory (SLEI)	Fraser, Giddings, & McRobbie, 1995; Fraser, McRobbie, Giddings, 1993	Upper Secondary and Higher Education	7	Student cohesiveness	Open-Endedness Integration	Rule clarity Material environment
Constructivist Learning Environment Survey (CLES)	Taylor, Dawson, & Fraser, 1995; Taylor, Fraser, & Fisher, 1997	Secondary	7	Personal relevance Uncertainty	Critical Voice Shared control	Student negotiation
What Is Happening In this Class? (WIHIC)	Fraser, Fisher, & McRobbie, 1996; Aldridge, Fraser, & Huang, 1999	Secondary	8	Student cohesiveness Teacher support Involvement	Investigation Task orientation Cooperation	Equity

The LEI was used to assess the actual environment of predominantly ‘teacher-centered’ classrooms. Preferred or personal forms had not been considered during the development of the LEI. The LEI is unusual in that it has a large number of scales (15) and with seven items per scale, resulting in 105 items altogether. Students choose from a four-point Likert response scale of *Strongly Disagree, Disagree, Agree,* and *Strongly Agree.* Reverse-scoring is used for some items. A sample item from the Speed scale is: “The pace of the class is rushed.”

2.3.1.2 Classroom Environment Scale (CES)

The *Classroom Environment Scale* (Moos, 1974, 1979; Moos & Trickett, 1987) emerged from an extensive research program at Stanford University in California, in which a variety of human environments were studied (psychiatric hospitals, military bases, prisons, university residences, and work settings). The CES is one of a set of nine separate instruments collectively called the Social Climate Scales (Moos, 1974). Original versions of the CES consisted of 242 and 208 items, but the final version had nine scales with 10 items in a True-False response format. A sample item from the Innovation scale is: “New ideas are always being tried out here.” Classroom environment was used as a dependent variable to evaluate a prevention program for reducing stress among students transferring from primary to secondary school (Felner, Ginter, & Primavera, 1982), to compare students’ actual versus preferred perceptions, and students’ actual versus teachers’ actual perceptions (Fisher & Fraser, 1983a; Fraser & Fisher, 1983b), and to examine student motivational levels (Greene, 1983), among other studies. The CES also was used to investigate associations between classroom environment and such outcome measures as academic achievement, attitudes (Fraser & Fisher, 1982b), absences and grades (Moos & Moos, 1978), and inquiry skills (Fisher & Fraser, 1983b; Fraser & Fisher, 1982b, 1982c).

An interesting area of learning environments research that was pioneered during use of the CES was conducted by Fraser and Fisher (1983a). Previously, person-environment fit and classroom environment studies were separate fields. However, Fraser and Fisher brought the two areas together by investigating the person-environment fit hypothesis of whether the relationship between achievement and actual classroom environment varies with the environment preferences of the class. In other words, do students (taken together as a class) achieve better when in their preferred classroom environments? Their sample consisted of

2,175 students in 116 eight- and ninth-grade science classes in Tasmania, Australia. Half of the students completed the actual form of the CES and half completed the preferred form. Two cognitive outcome measures from the *Test of Enquiry Skills* (Fraser, 1979) and one affective outcome measure from the *Test of Science-Related Attitudes* (Fraser, 1981) were administered in a pretest-posttest design and given to all students. Also, student general ability was measured near the middle of the year. The class mean was chosen as the unit of analysis because the CES scales reflect wording designed for measuring class-level environment characteristics. Findings suggested that actual-preferred congruence at the class level could be as important as the nature of actual classroom environment in predicting class achievement of important cognitive and affective aims. The relationship between achievement and an actual classroom environment scale was more positive for classes whose students had a higher preference for that scale than in classes whose students had a lower preference.

2.3.1.3 My Class Inventory (MCI)

My Class Inventory (Fisher & Fraser, 1981; Fraser et al., 1982; Fraser & O'Brien, 1985) is a simplified version of the LEI for use among children aged 8—12 years and students experiencing reading difficulties, or when English is the second language. The MCI contains wording that is suitable for young children, includes only five of the LEI's 15 scales, and has 38 items in total (although the number of items per scale can vary). The response format consists of Yes—No. Sample items include: "Children are always fighting with each other" (Friction) and "Children seem to like the class" (Satisfaction).

During its early use, the MCI was used in curriculum evaluation studies involving cooperative grouping (Talmage, Pascarella, & Ford, 1984), an inservice course on investigative approaches to mathematics teaching (Talmage & Hart, 1977), and comparing mainstreamed special education classes versus general education classes on students' perceptions of the learning environment. Several studies investigated associations between classroom environment and achievement (Payne, Ellett, Perkins, Klein, & Shellinberger, 1974; Talmage & Walberg, 1978), between classroom environment and school attendance (Ellett, Payne, Masters, & Pool, 1977; Ellett & Walberg, 1979), and between classroom environment and student attitudes (Mink & Fraser, in press). The MCI was not used in science classrooms, however, until Fisher and Fraser (1981) validated the MCI with 2,305 seventh grade students in Tasmania, and improved the instrument's validity and reliability (i.e., they conducted an item analysis and removed faulty items thereby improving scale reliability). Their 'short' form of the MCI consisted of 25 items, and completion only took 10 to 15 minutes. The researchers examined associations between the classroom learning environment and the student outcomes of inquiry skills, understanding the nature of science, and attitudes (Fraser & Fisher, 1982a, 1982b, 1982c).

Classroom learning environment studies that made use of the MCI continued throughout the 1980s. Fraser (1984) used the short form of the MCI to compare students' actual versus preferred, and teachers' actual versus preferred, perceptions of the learning environment with 22 Grade 3 classrooms in Sydney, Australia. This study replicated findings from secondary school classrooms in that both students and teachers preferred a more favorable classroom environment than the one they were actually experiencing, and teachers perceived a more favorable environment than their students in the same classrooms. Interestingly, these findings also replicate patterns found in other human milieus such as psychiatric hospitals (Moos, 1972; Moos & Bromet, 1978), prisons (Waters & Megathlin, 1981), and general work settings (Moos, 1981). A unique study involving university physics students was conducted by Lawrenz and Munch (1984) in which they investigated student grouping in a laboratory classroom and formal reasoning ability. They found "that the method of laboratory grouping did not affect students' perceptions of the classroom learning environment" (in Fraser, 1986b, p. 146).

In the first study to use hierarchical linear modeling in learning environments research, Goh et al. (1995) modified the MCI to a three-point frequency response format consisting of *Seldom, Sometimes* and *Most of the Time*, and added a Task Orientation scale (along with Cohesion, Competition and Friction) in their study of 1,512 fifth grade mathematics students in Singapore. They used both multiple linear regression analysis and hierarchical linear modeling to investigate associations between the learning environment and the student outcomes of attitude and achievement. The advantage of using hierarchical linear modeling is that it can analyze 'nested' data. During multiple linear regression analyses at the student level, the nesting of students within classrooms is ignored and this can lead to an underestimation of standard errors and a greater risk of Type I errors (Raudenbush, 1988). When the data are aggregated at the class level of analysis using the class means, information is lost about individual differences. Using multiple linear regression analysis, the researchers found a statistically significant association between attitudes and the environment scales of Cohesion, Friction, and Task Orientation, using the individual as the unit of analysis and when each of the other scales was mutually controlled. Using the class mean as the unit of analysis, none of the scales were significantly related to attitudes. For student achievement, Friction was a significant independent predictor of attitudes for each unit of analysis. Using hierarchical linear modeling, most of the statistically significant results were replicated, as well as being consistent in direction for both levels of analysis. The two significant associations in the multiple regression analyses that were not replicated in the hierarchical linear modeling analyses were between Cohesion and achievement and between Task Orientation and attitude, both at the individual level of analysis. Overall, Friction accounted for the largest amount of variance in student outcomes, and Competition appeared to be weakly associated with student outcomes.

Several important studies have explored how science teachers might use learning environments research in guiding practical improvements in science classrooms (Fisher, Fraser, & Bassett, 1995; Moss & Fraser, 2002; Sinclair & Fraser, 2002; Thorp, Burden, & Fraser, 1994; Yarrow, Millwater, & Fraser, 1997; Roth, 1998). One early study was conducted by Fraser and Fisher (1986) in which they used short forms of the MCI, CES, and the *Individualized Classroom Environment Questionnaire* (ICEQ). First, the short form of the MCI was validated with a sample of 758 Grade 3 students in an outer suburb of Sydney, Australia (Fraser & O'Brien, 1985). Second, a Grade 6 elementary teacher with 26-lower ability students used actual and preferred forms of the MCI to guide improvements in the environment of her classroom. The teacher incorporated five steps in order to make improvements: (1) assessment using the actual and preferred forms of the MCI, (2) feedback in the form of profiles comparing any differences between preferred and actual perceptions, (3) reflection and discussion with the researchers prior to introducing an intervention aimed at reducing the level of Competitiveness and increasing the level of Cohesiveness, (4) intervention of two months' duration, and (5) reassessment in which the actual form of the MCI was readministered at the end of the intervention. The case study indicated that, during the time of the intervention, a statistically significant reduction in actual-preferred discrepancy occurred for the scales of Competitiveness and Cohesiveness (i.e., the two scales on which change was being attempted), but nonsignificant changes occurred on the other three MCI scales.

An area of learning environments research that needs more attention is identification of exemplary practice among science teachers. The only known study was conducted by Fraser (1986a) in which he used short forms of the CES and the MCI, together with qualitative methods, to identify high-quality elementary and high school science and mathematics teachers in Western Australia. The study's purpose was to investigate key characteristics common to exemplary teaching and to compare these characteristics with classroom environments of ordinary teachers. The actual environments of two exemplary elementary teachers were compared with the actual environment of a control group of classes. Findings indicated that exemplary and ordinary science teachers can be differentiated in terms of the psychosocial environments of their classrooms.

In a recent study that made use of the MCI, Majeed et al. (2002) investigated the learning environment and its association with student satisfaction among 1,565 lower secondary mathematics students in Brunei Darussalam. The longer version of the MCI was modified for the Bruneian context by using only three scales—Cohesiveness, Difficulty, and Competitiveness. This study is important because the factorial validity of the MCI had not previously been established in earlier research in other countries. The study found a satisfactory factor structure for the three-scale version of the MCI, that students generally perceived a positive learning environment in their mathematics classes, that girls and boys perceived the learning environment differently (boys had slightly more positive perceptions), and that statistically significant associations exist between the learning environment and satisfaction both at the student and class levels for most MCI scales. Also of interest was the finding that Bruneian mathematics classrooms have a rather high level of Competition, although Competition was not statistically significantly related to Satisfaction using the class mean as the unit of analysis in either a simple and multiple correlation analysis. Student Cohesiveness had the strongest (and a positive) association with Satisfaction, while Difficulty had a significant negative association with Satisfaction in all analyses.

2.3.2 Student-Centered Classroom Learning Environment Instruments—ICEQ, CUCEI, QTI, and CLES

Whereas Section 2.3.1 reviewed early and historically-important classroom learning environment instruments that were 'teacher-centered', the following section reviews four additional instruments that were developed and validated after the LEI, CES, and MCI. All four of these more recent instruments were designed with ‘student-centered’ classrooms in mind. Each instrument (ICEQ, CUCEI, QTI, and CLES) is described in terms of conceptualization of the instrument, number of items, number of scales, and style and number of response options. Numerous studies associated with each instrument are reviewed in a subsection devoted to each questionnaire. The SLEI and WIHIC are reviewed in Sections 2.4 and 2.5 in greater detail than the previously-mentioned seven instruments because I used scales from these questionnaires for my study.

2.3.2.1 Individualized Classroom Environment Questionnaire (ICEQ)

The *Individualized Classroom Environment Questionnaire—ICEQ* (Fraser, 1990; Rentoul & Fraser, 1979) was the first instrument that was ‘student-centered’ and that assessed the environment of individualized, open or inquiry-based classrooms. The final published version of the ICEQ (Fraser, 1990) has five scales and 50 items, and used a five-point frequency response scale of *Almost Never, Seldom, Sometimes, Often* and *Very Often.* A short form consisting of 25 items was also developed (Fraser & Fisher, 1986). Typical items are: “The teacher considers students’ feelings” (Personalization) and “Different students use different books, equipment and materials” (Differentiation).

Several studies used the ICEQ to investigate associations between student outcomes and environment. Outcome measures included inquiry skills (Fraser & Fisher, 1982b; Rentoul & Fraser, 1980), attitudes (Fraser & Butts, 1982; Fraser & Fisher, 1982b; Wierstra, 1984), achievement (Wierstra, 1984), and anxiety (Fraser, Nash & Fisher, 1983). Studies that used classroom environment perceptions as criterion variables looked at an innovation in individualization (Fraser, 1980), the introduction of a new physics curriculum (Kuhlemeier, 1983; Wierstra, 1984), the differences between students’ actual and preferred perceptions, and teachers’ actual and perceived perceptions (Fisher & Fraser, 1983a; Fraser, 1982), and changes in beginning teachers’ preferences for individualization (Rentoul & Fraser, 1981).

As mentioned in Section 2.3.1.2—Classroom Environment Scale, using both actual and preferred forms of an instrument such as the CES and/or ICEQ can allow exploration of whether students achieve better when there is a higher similarity between the actual classroom environment and that preferred by students. Fraser and Fisher (1983a, 1983b) used the ICEQ with 116 class means from an earlier study conducted in Tasmania (Fraser & Fisher, 1982b) and predicted posttest achievement from pretest performance, general ability, the five ICEQ scales and five variables indicating actual-preferred interaction. Person-environment fit studies such as this have practical implications for teachers wanting to conduct action research in their own classrooms. Teachers can conceivably improve class achievement of certain outcomes by changing the actual classroom environment in ways which make it more congruent with that preferred by the class.

The ICEQ can be used on its own and also in conjunction with other questionnaires such as the CES (Fraser & Fisher, 1982b). Fraser and Fisher used a sample of 1,083 junior high school students in 116 classrooms in Tasmania, Australia to investigate associations between the learning environment and the outcomes of attitude and inquiry skills using six types of analyses. Attitude was measured using six scales from the *Test of Science-Related Attitudes* (Fraser, 1981), while the *Test of Enquiry Skills* (Fraser, 1979) was used to measure three cognitive outcomes. It was found that the ICEQ and CES each made an important unique contribution to criterion variance, attesting to the usefulness of including both instruments within the same study. Additional details on this study, with a focus on environment-attitude associations are discussed in Section 2.6.2.

2.3.2.2 College and University Classroom Environment Inventory (CUCEI)

The *College and University Classroom Environment Inventory* (Fraser & Treagust, 1986; Fraser et al., 1986) was developed for use in small, seminar classes at the college and university level. The CUCEI has seven seven-item scales. Each item has four responses (*Strongly Agree, Agree, Disagree, Strongly Disagree*) and the polarity is reversed for about half of the items. Typical items are: “Activities in this class are clearly and carefully planned” (Task Orientation) and “Teaching approaches allow students to proceed at their own pace” (Individualization). Two studies used the CUCEI to investigate associations between satisfaction and classroom learning environment (Fraser, Treagust, & Dennis, 1984; Glenn, 1975). Like other instruments, the CUCEI can be used in four different forms (student actual, student preferred, teacher actual, teacher preferred).

2.3.2.3 Questionnaire on Teacher Interaction (QTI)

The *Questionnaire on Teacher Interaction* (Créton et al., 1990; Wubbels et al., 1991; Wubbels & Levy, 1993) is a unique classroom learning environment instrument because it is the only questionnaire that assesses the interpersonal relationship between a teacher and his or her students. The QTI is also unusual in that its design was modeled on a 'systems approach to communication' (Watzlawick, Beavin, & Jackson, 1967) and a general model for interpersonal relationships proposed by Leary (1957). Wubbels, Créton, and Hooymayers (1985) modified Leary's theoretical model to the context of education and renamed the dimensions, which they called Influence (Dominance-Submission) and Proximity (Opposition-Cooperation). Wubbels et al.'s (1985) model for interpersonal teacher behavior has eight scales called Leadership, Helpful/Friendly, Understanding, Student Responsibility and Freedom (positive attributes of teacher-student relationships), and Uncertain, Dissatisfied, Admonishing and Strict (negative attributes of teacher-student relationships). Each item has a five-point response scale ranging from Never to Always. Typical items are: "She/he gives us a lot of free time" (Student Responsibility and Freedom) and "She/he gets angry" (Admonishing).

The QTI has been used extensively in The Netherlands in many studies involving preservice and inservice teacher training (Brekelmans, Wubbels, & Den Brok, 2002), as well as with students (Brekelmans, Den Brok, Bergen, & Wubbels, 2004; Den Brok, Wubbels, van Tartwijk, Veldman, & de Jong, 2004). It has also been used in Brunei (Fisher, Scott, Den Brok, 2004; Khine & Fisher, 2002; Riah & Fraser, 1998; Scott & Fisher, 2001, 2004), the US (Wubbels & Levy, 1993), Australia (Dorman, 2004; Evans, 1998; Fisher, Henderson, & Fraser, 1995; Rickards, Den Brok, & Fisher, 2004), Singapore (Fisher et al., 1997; Goh & Fraser, 1996; 1998; 2000; Quek et al., 2001), Korea (Kim et al., 2000; Lee & Fraser, 2001), Thailand (Wei & Onsawad, 2004), and Indonesia (Soerjaningsih et al., 2001). An entire chapter (Brekelman et al., 2002) in *Studies in Educational Learning Environments: An International Perspective* (Goh & Khine, 2002) is devoted to the QTI and related studies.

2.3.2.4 Constructivist Learning Environment Survey (CLES)

The *Constructivist Learning Environment Survey* (Taylor et al., 1995; Taylor et al., 1997) was developed in response to the recent trend of teacher preparation educators and institutions promoting a constructivist epistemology. Constructivists believe that all learning is a cognitive process in which learners must construct their own understanding of a topic or concept by either assimilating or accommodating ‘new’ knowledge with what they already know (Richardson, 1997). Learning is aided (or hindered) through an individual’s interactions with the physical and social world. Wilson (1996, p. 5) defines a constructivist learning environment as a place “where learners may work together and support each other as they use a variety of tools and information resources in their guided pursuit of learning goals and problem-solving activities”. The CLES helps teachers and researchers to assess the degree to which a classroom reflects a constructivist epistemology, and, if desired, to change teaching practice to a more constructivist style.

The CLES has 30 items with five response alternatives ranging from Almost Never to Almost Always. The five scales are called Personal Relevance, Uncertainty of Science, Critical Voice, Shared Control, and Student Negotiation. Typical items include: “I learn that science has changed over time” (Uncertainty of Science) and “I ask other students to explain their thoughts” (Student Negotiation).

In the USA, Roth and Roychoudhury (1994b) investigated physics students’ epistemologies and views about knowing and learning using the CLES. Dryden and Fraser (1996) evaluated a large-scale urban systemic reform initiative using several instruments including the CLES. The CLES was cross-validated with 1,600 students in 120 Grade 9—12 science classes in Dallas, Texas. In the same city, Nix, Ledbetter, and Fraser (2004) used three modified forms of the CLES to assess the perceived degree of constructivist teaching among university science teacher educators and in high school science classrooms taught by the teachers who were participating in a field-based university science course. Nix et al. conducted a multilevel evaluation of the course that also had a heavy emphasis on technology. Similar to Nix et al.’s study, Johnson and McClure (2002) used the CLES to investigate the classroom learning environment of beginning science teachers in Minnesota. The study involved 290 elementary, middle, and high school preservice and inservice science teachers.

Roth (1998) conducted a small-scale study in Canada in which he used the CLES as a tool to bring about reform in a science department in a private high school during a three-year period. The reform consisted of a change to student-centered open-inquiry science classrooms. Two classes of Grade 8 students (*N*=43) taught by the same teacher were monitored in terms of students’ perceptions of their learning environment and their cognitive achievement. Using a combined quantitative and qualitative approach, Roth concluded that a mix of using the CLES, videotaped lessons, student interviews, and test results was crucial for the teachers and researcher to understand the complex nature of classroom learning environments.

The CLES has been also validated in several Asian countries. In Singapore, Wilks (2000) expanded and modified the CLES for use with 1,046 junior college students studying English. The questionnaire displayed good factorial validity and internal consistency reliability and each scale, including two new ones that were added called Ethic of Care and Political Awareness, differentiated significantly between the perceptions of students in different classrooms. Kim et al. (1999) translated the CLES into the Korean language and gave it to 1,083 science students. The translated version had good factorial validity for the original five scales. Lee and Fraser (2001) also used a Korean version with 440 Grade 10 and 11 science students. The CLES was also translated into Mandarin during a large cross-national study in Taiwan and Australia. Aldridge, Fraser, Taylor, and Chen (2000) administered the English version to 1,081 science students in 50 classes in Australia, while the new Mandarin version was given to 1,879 science students in 50 classes in Taiwan.

The CLES has been used in South Africa as well, where learning environments research is just emerging. Sebela, Fraser, and Aldridge (2003) conducted a large-scale study with 1,864 students in 43 Grade 4—9 classes. Again, the CLES's reliability and factorial validity were strongly supported.

Overall, the seven classroom environment instruments reviewed in this section and in Section 2.3.1 provide a solid foundation for the classroom learning environments field. Many of these instruments are still being used and modified in contemporary studies in a variety of countries, at various grade levels, and in several different subject areas. Their reliability and validity continue to withstand the test of time.

2.4 Development, Validation and Use of the Science Laboratory Environment Inventory (SLEI)

Whereas Section 2.3 gave an overview of seven of nine historically-important classroom learning environment instruments, this Section and Section 2.5 provides considerable detail about the last two questionnaires, namely the *Science Laboratory Environment Inventory* and *What Is Happening In this Class?* This is because, in my study, I used scales from these two instruments to produce a modified laboratory learning environment questionnaire that was suitable for the science course for prospective elementary teachers in my research.

Initial development of the *Science Laboratory Environment Inventory* was aided by a review of the literature, examination of existing learning environment instruments, and feedback from science teachers and students who looked at draft versions of the SLEI (Fraser et al., 1992). The SLEI has 35 items that are categorized into five scales called Student Cohesiveness, Open-Endedness, Integration, Rule Clarity, and Material Environment. Table 2.2 describes each of the five scales on the SLEI, and provides a sample item from each scale.

Scores of 1 to 5 are allocated to the frequency responses of *Almost Never, Seldom, Sometimes, Often,* and *Very Often*, respectively. However, 13 of the 35 items are reverse scored, meaning that 5 is given for *Almost Never* and 1 for *Very Often*, and so on. This is done to reduce the likelihood of students biasing their responses to either end of the response scale (e.g., *Almost Always*, *Almost Never*) (Taylor et al., 1997). A '3' is given to omitted or incorrectly-answered items.

The *actual* or current situation in a science laboratory class is determined using the *actual* form of the SLEI. This is often compared with what students would *prefer* in an ideal scenario in a science laboratory class with the *preferred* form. Wording is only slightly altered in the two forms. For example, Item #1 on the *actual* form would read: "We get on well with students in this laboratory class", while the same item on the *preferred* form would be: "We would get on well with students in this laboratory class."

Table 2.2
Descriptive Information for Each Scale of the SLEI

Scale Name	Description	Sample Item
Student Cohesiveness	Extent to which students know, help and are supportive of one another.	I get along well with students in this laboratory class. (+)
Open-Endedness	Extent to which the laboratory activities emphasize an open-ended divergent approach to experimentation.	In my laboratory sessions, the teacher decides the best way for me to carry out the laboratory experiments. (–)
Integration	Extent to which the laboratory activities are integrated with non-laboratory and theory classes.	I use the theory from my regular science class sessions during laboratory activities. (+)
Rule Clarity	Extent to which behavior in the laboratory is guided by formal rules.	There is a recognized way for me to do things safely in this laboratory. (+)
Material Environment	Extent to which the laboratory equipment and materials are adequate.	I find that the laboratory is crowded when I am doing experiments. (–)

+ Items designated (+) are scored 1, 2, 3, 4, and 5, respectively, for the responses Almost Never, Seldom, Sometimes, Often and Very Often.
– Items designated (-) are scored 5, 4, 3, 2, and 1, respectively, for the responses Almost Never, Seldom, Sometimes, Often and Very Often.

From Fraser et al. (1992b, p. 3)

The SLEI was the first instrument to have separate *class* and *personal* forms. Item wording, as illustrated above, forced students to respond based on their perceptions of the class as a single entity (Taylor et al., 1997). A personal form assesses a student’s perceptions of his or her role within the classroom, information that is necessary for case studies of individual students or subgroups within classes (e.g., females and males). Item #1, therefore, would be worded as “I get on well with students in this laboratory class” on the actual personal form and as “I would get on well with students in this laboratory class” on the preferred personal form.

The following five subsections describe specific studies that utilized the *Science Laboratory Environment Inventory*.

2.4.1 Cross-National Studies with the SLEI

The first version of the SLEI for secondary and college science laboratory classes was developed and validated in a large cross-national study that involved over 5,000 students in six countries—USA, Canada, Australia, England, Israel, and Nigeria (Fraser et al., 1992a, 1993, 1995; Fraser & Griffiths, 1992; Fraser & Wilkinson, 1993). Table 2.3 provides a description of each country's sample size in this landmark study.

The six-country cross-national study was the first research in the learning environments field to analyze the unique instructional setting of science laboratories. Fraser et al. (1995) reported five general findings. First, the most noteworthy finding for science teachers and educators was that laboratories in all six countries were dominated by closed-ended activities. An example from the *actual personal* form of an item from the Open-Endedness scale reads: "There is opportunity for me to pursue my own science interests in this laboratory class."

Table 2.3
Description of the Cross-National Sample

	Sample Size		
Country	Students	Classes	Schools or Universities
Australia	2,173	135	19
USA	1,604	65	5
Canada	605	23	10
England	214	17	3
Israel	463	18	12
Nigeria	388	11	4
TOTAL	5,447	269	53

From Fraser et al. (1992a, 1993)

Second, when *class* and *personal* perception scores from the SLEI were compared, *class* scores were more favorable than *personal* scores (although this difference was small in magnitude). As mentioned earlier, use of the *personal* form makes it easier to analyze individual or subgroup perceptions, rather than only focusing on the entire class. An example of this was illustrated in Fraser et al.'s (1995) third finding in which females perceived their laboratory learning environment slightly more favorably than their male counterparts, another result that supports previous research (Lawrenz, 1987).

Fourth, the SLEI can differentiate between psychosocial perceptions of students in different classrooms. This indicates that students in the same class perceive their laboratory learning environment similarly, and mean within-class perceptions are distinct from classroom to classroom. The fifth finding was that the *actual* form of the SLEI was positively related with student attitudes (except Open-Endedness for some subsamples). Of special interest in the cross-national study was the finding that, when classes scored high on Student Cohesiveness and Integration, more favorable attitudes toward laboratory work were found. This finding has implications for my study because I also investigated associations between the learning environment in the course, *A Process Approach to Science* (SCED 401), and attitudes towards science among the 525 female prospective elementary teachers sampled.

Fraser and Griffiths (1992) drew on the six-country cross-national study to report and compare data specifically for Canadian schools and universities. They found that the Canadian results were comparable to the cross-national results. In a similar vein, Fraser and Wilkinson (1993) analyzed the data for British schools and universities. Again, the English results compare favorably with the cross-national results.

2.4.2 Cross-Validation Studies with SLEI in Australia

After the cross-national study in six countries, a refined version of the SLEI evolved in which problematic items were removed from the instrument. McRobbie and Fraser (1993) used the refined version of the SLEI in Brisbane, Australia, with 1,594 senior secondary chemistry students in 92 classes and 52 schools, to conduct further studies of outcome-laboratory learning environment relationships.

In addition to completing the SLEI, a subsample of 596 students also completed a Likert-style questionnaire assessing chemistry-related attitudes. The Likert-style questionnaire was a blend of items from the *Test of Science-Related Attitudes* (TOSRA) (Fraser, 1981) and new items. The four scales were entitled Enjoyment of Chemistry, Social Implications of Chemistry, Normality of Chemists, and Career Interest in Chemistry. The attitude questionnaire was used to investigate associations between attitudinal outcomes and the laboratory learning environment, as has been commonly done in previous research. A strong and consistent attitude-learning environment association was found between the four SLEI scales of Student Cohesiveness, Integration, Rule Clarity, and Material Environment and most of the attitude scales. Notably, Open-Endedness had a significant negative correlation with the attitude scale of Normality of Chemists. This latter finding suggests that attempting to increase the number of open-ended activities in the science laboratory can backfire, and inadvertently and adversely affect students' attitudes.

A second subsample of 591 students responded to two cognitive measures along with the SLEI. These were based on Fraser's (1979) multiple-choice *Test of Enquiry Skills* and an item bank (Australian Council for Educational Research, 1978). Thus, the cognitive measures evolved into two scales, one called Conclusions and Generalizations, and the second called Design of Experimental Procedures. During simple correlation analyses, positive correlations were found between each laboratory learning environment scale and each cognitive measure, except that perceived Open-Endedness was linked with lower scores on the Conclusions and Generalizations scale for the analysis involving individuals. Using canonical correlation analyses, scores on both Conclusions and Generalizations and Design of Experimental Procedures were higher when Integration and Material Environment were favorable.

A study investigating biology laboratory classrooms and attitudes towards science was conducted in Tasmania, Australia (Fisher, Henderson, & Fraser, 1997; Henderson, Fisher, & Fraser, 2000) with 489 senior secondary students in 28 classes. Students completed the SLEI, the QTI, two scales from the *Test of Science-Related Attitudes* (TOSRA), a written examination, and several practical skills tests. The most interesting finding was that associations were strongest between learning environment and attitudes, rather than between learning environment and either cognitive achievement or practical performance outcomes. The Tasmanian study cross-validated the reliability and validity of the SLEI specifically in biology classes. Another interesting finding was that students with more than one science laboratory class had more favorable learning environment and attitude scores. Lastly, the authors reported that teacher interpersonal behavior, as measured by the QTI, and laboratory learning environment, as measured by the SLEI, provided complementary descriptors of the biology classroom and that using both instruments provided a better overall picture of biology teaching and learning. Further discussion of this study is provided in Section 2.6.2 that reviews environment-attitude associations.

A smaller study comparing biology, chemistry, and physics laboratory classroom environments was completed in Tasmania (Fisher, Harrison, Henderson, & Hofstein, 1998). A total of 387 students in 20 classes completed the *actual* form of the SLEI, while a content analysis of textbooks and practical laboratory manuals was also carried out. This study showed that the SLEI can distinguish between the three science disciplines. Three significant differences were found between biology, chemistry, and physics: (1) physics laboratory environments were more open-ended than chemistry or biology laboratories, (2) Rule Clarity was greatest in chemistry, and (3) there was greater Integration between theory and practical work in chemistry and physics laboratory classes compared to biology.

2.4.3 Laboratory Classroom Learning Environments in Asia

Wong and Fraser (1994, 1996) and Wong et al. (1997) cross-validated a slightly modified version (the word 'chemistry' was used instead of 'science') of the *personal* form of the SLEI during the first large-scale learning environment research conducted in an Asian country. A total of 1,592 tenth grade students and 56 teachers at 28 schools in Singapore were involved. In addition to the SLEI, Wong and colleagues used a 30-item, three-scale *Questionnaire of Chemistry-Related Attitudes* (QOCRA) a modification from Fraser's (1981) TOSRA. The study was also distinctive because it later reanalyzed the data using Hierarchical Linear Modeling (HLM) (Raudenbush, 1988). The authors found that the SLEI, modified for use specifically in chemistry laboratories, was reliable and valid for assessing students' and teachers' perceptions, that cross-validation support was provided for use in Singapore, and that HLM results were similar to the multiple regression analyses. (Further details on environment-attitudes associations and HLM are reviewed in Section 2.6.2.)

Many similarities were found when the Singaporean data were compared with the six-country cross-national study. As with the general findings of the cross-national study, Wong and Fraser (1994, 1996) and Wong et al. (1997) found that the *preferred* scores were slightly higher than *actual* scores, that females viewed the laboratory environment slightly more favorably than males (except for Open-Endedness), and that there were positive associations between learning environment and attitudinal outcomes (again, except for Open-Endedness). Wong and Fraser also looked at teachers' perceptions of their own laboratory environments. Perceptions of the two groups differed, with the teachers rating the overall laboratory learning environment more favorably than their students, which provided a replication of the cross-national study. Specifically, teachers and students had similar perceptions of Student Cohesiveness, Integration, and Material Environment, while teachers perceived a significantly lower level of Open-Endedness and a higher level of Rule Clarity than their students.

With regard to differences between the Singaporean data and the six-country cross-national study, some interesting differences were noted. Chemistry laboratory learning environments in Singapore were found to have higher levels of Rule Clarity and lower levels of Integration and Material Environment than Australian, American, Canadian, and Israeli classes. Singaporean students also rated Student Cohesiveness higher than students in Australia, Canada, or Israel. Open-Endedness was rated lower in Singapore compared to Australia, USA, and Canada, but not as low as in Israel. Lastly, only Singaporean males had more favorable perceptions of Open-Endedness than females.

Several other studies in Asia support and complement Wong and Fraser's, and Wong et al.'s study of chemistry laboratory environments in Singapore. Quek et al. (2001) compared 497 gifted and non-gifted chemistry students' perceptions in Singapore. Riah and Fraser (1998) cross-validated the English version of the SLEI with 644 tenth grade chemistry students in Brunei Darussalam. An interesting finding was that "…Open-Endedness was positively associated with students' attitudinal outcomes but negatively associated with students' achievement in Chemistry" (Khine, 2002, p. 141). The study suggested that, when teachers provide more autonomy and independence and allow students to do their own investigations, work cooperatively in theory classes, and give open-ended practicals in laboratory classes, the effects might not be positive. Nevertheless, one must wonder if this finding and suggestion is culturally dependent.

Poh (1995) also conducted a study in Brunei in which the quality of biology laboratory work was evaluated in terms of students' process skills development and their perceptions of the learning environment. The study involved 220 biology students in nine government schools, and the use of two instruments, one of them including the SLEI. The researcher found that students had little opportunity to practice higher-order process skills, that laboratory activities were often close-ended, and that female students perceived their laboratory learning environment more favorably than male students (Khine, 2002).

Learning environment studies in Korea have also been on the rise during the past decade. The first study was conducted in 1993 by Yoon who investigated the relationship between the psychosocial environment of laboratory classrooms and learning outcomes. Other Korean studies that followed Yoon's work involved diverse contexts (primary, junior high, senior high, universities, various 'streams' of science classes, theory lessons and laboratory lessons, and curricular reforms), and a selection of scales from several different instruments. A translated version of the SLEI exhibited with strong factorial validity and patterns from previous research were replicated (e.g., low Open-Endedness scores and significant associations with attitudes) (Kim & Kim, 1995, 1996; Kim & Lee, 1997; Lee & Fraser, 2001, 2002). Specifically, Kim and her colleagues have compared perceptions of students at various school levels, as well as Korean students' perceptions relative to students from other countries. Of particular interest and relevance to my study was the finding that prospective primary teachers enrolled in a teachers' college had far less favorable perceptions of their laboratory classroom environments compared with tertiary level students in other countries. In another study (Kim & Kim, 1996), researchers found that the gap between *actual* and *preferred* perceptions among 276 middle school and 263 high school students was greatest for the scale of Open-Endedness. Kim and Kim found that students preferred a more open-ended format for their laboratory lessons compared to what they were actually experiencing. As science and technology education continues to play a central role in Korean society and culture, along with a wave of new curricular reforms every few years, science learning environments research in Korea will probably continue to expand over the next decade.

2.4.4 Laboratory Classroom Learning Environments in Israel

Recently, Hofstein et al. (2001) analyzed inquiry-type laboratories in high school chemistry classes in Israel. The study was intriguing because Israeli students rated Open-Endedness the lowest of all the six countries involved in the original cross-national study. The authors conceded that: "We operate in an era in which we have observed a revival of the inquiry approach in science teaching and learning" (p. 206). Their research was unique in the learning environments field, as no other study had compared the results of introducing inquiry-type laboratory activities with a control group experiencing closed-ended laboratory activities.

The subjects in the Israeli study included 130 eleventh grade students in an inquiry group, 185 eleventh grade students in the control group, and 10 teachers who received training for the inquiry-based teaching program. The researchers used a longer, Hebrew version of the SLEI consisting of 72 items and eight scales (additional scales included Teacher Supportiveness, Involvement, and Organization). Significant differences between the inquiry and control groups were found, particularly with the *actual* form. Specifically, Open-Endedness, Involvement, and Material Environment were scored higher for the inquiry group, while Integration was higher for the control group. Differences between the *actual* and *preferred* forms were lower in the inquiry group for Open-Endedness, Involvement, and Integration. The researchers also conducted interviews with students and teachers from the inquiry-type laboratory group. The inclusion of qualitative data in the study revealed that both students and teachers felt "…that introducing inquiry type approaches to the chemistry laboratory had a positive impact on the learning environment" (p. 204).

Hofstein et al. (1996) compared biology and chemistry laboratory environments, *actual* and *preferred* environments, and male and female perceptions in 15 eleventh grade classrooms (*N*=371) in Israel. Again, the Israeli researchers used a longer Hebrew version of the SLEI consisting of 70 items and eight scales. The authors confirmed Fisher et al.,'s (1998) finding that the SLEI can distinguish between disciplines for some scales. For the Israeli sample, differences were found for the scales of Integration and Open-Endedness. Biology students perceived their laboratory environments as being more open-ended compared to the chemistry students. On the other hand, chemistry students rated Integration and Rule Clarity more highly. However, this finding was not surprising because the curricula for biology and chemistry were developed with different objectives in mind. In biology, students use the Biological Sciences Curriculum Study (BSCS, 1963) yellow version, which utilizes an inquiry approach. Chemistry students use *Chemistry A Challenge* (Ben-Zvi & Silberstein, 1985) that focuses on closed-ended tasks.

When comparing *actual* versus *preferred* laboratory environments, Israeli chemistry students scored significantly higher on the scales of Integration and Organization than the biology students. Overall, however, both biology and chemistry students *preferred* a more favorable learning environment on all scales than what they were *actually* experiencing.

Gender differences were found in the *actual* biology learning environment, but not in the *actual* chemistry environment. Girls rated their *actual* biology classes more favorably than boys on the scales of Teacher Supportiveness, Involvement, and Student Cohesiveness, but the opposite was true for Open-Endedness. Greater gender differences were found with the *preferred form*, as predicted. In the *preferred* chemistry environment, boys' mean scores for Open-Endedness were higher compared to girls. In the *preferred* biology environment, girls' mean scores for seven of the eight scales (except Open-Endedness) were higher.

2.5 Development, Validation and Use of What Is Happening In this Class? (WIHIC)

Although having the large selection of learning environment surveys as listed in Table 2.1 has its advantages, there is some overlap in what the surveys measure and some scales and/or items are not pertinent in current classroom settings (Aldridge et al., 1999). Consequently, the *What Is Happening In this Class?* (WIHIC) was developed by Fraser et al. (1996) to combine scales from past questionnaires with contemporary dimensions to bring parsimony to the field. The WIHIC has emerged as the most-widely used instrument in the learning environments field in the last five years. Like the SLEI, the WIHIC has actual and preferred, and class and personal, forms.

The first version of the WIHIC was a 90-item nine-scale instrument that was refined using a sample of 355 junior high school science and mathematics students (Fraser et al., 1996) from Australia. After statistical analysis and interviews with students, the WIHIC evolved into *class* and *personal* forms consisting of seven scales called Student Cohesiveness, Teacher Support, Involvement, Investigation, Task Orientation, Cooperation, and Equity (the scales of Autonomy/Independence and Understanding were omitted). In a second trial version of the WIHIC, the Autonomy/Independence scale was reinstated in an 80-item eight-scale version. Table 2.4 provides a description of each scale and shows a sample item for the 'final' version that is commonly used in current studies (56 items in seven scales).

Like the SLEI, the WIHIC has a five-point frequency response scale of *Almost Never, Seldom, Sometimes, Often,* and *Almost Always.* But, unlike the SLEI, no WIHIC items are reverse-scored or negatively-worded because recent research revealed that reverse-scoring was not effective. Barnette (2000) made the recommendation to use positively or directly-worded stems (i.e., statements do not contain the word 'not') with bi-directional response options (i.e., the use of Likert response alternatives that represent opposite directions, half going from *Strongly Agree* to *Strongly Disagree* and half going from *Strongly Disagree* to *Strongly Agree*). WIHIC items are positively-worded but response options all go in one direction from *Almost Never* to *Almost Always*.

The following five sections describe specific studies that utilized *What Is Happening In this Class?* beginning with studies most relevant to the present research.

Table 2.4
Descriptive Information for Each Scale of the WIHIC

Scale Name	Description	Sample Item
Student Cohesiveness	Extent to which students know, help, and are supportive of one another	I make friendships among students in this class.
Teacher Support	Extent to which the teacher helps, befriends, trusts, and shows interest in students	The teacher takes a personal interest in me.
Involvement	Extent to which students have attentive interest, participate in discussions, perform additional work, and enjoy the class	I discuss ideas in class.
Investigation	Emphasis on the skills and processes of inquiry and their use in problem solving and investigation	I carry out investigations to test my ideas.
Task Orientation	Extent to which it is important to complete activities planned and to stay on the subject matter	Getting a certain amount of work done is important to me.
Cooperation	Extent to which students cooperate rather than compete with one another on learning tasks	I cooperate with other students when doing assignment work.
Equity	Extent to which students are treated equally by the teacher	The teacher gives as much attention to my questions as to other students' questions.

All items are scored 1, 2, 3, 4, and 5, respectively, for the responses Almost Never, Seldom, Sometimes, Often and Almost Always.

2.5.1 Studies with WIHIC at the University Level

Of the many learning environment studies conducted recently using the WIHIC, only one study involved preservice or inservice elementary teachers (Pickett & Fraser, 2004). Yarrow et al. (1997) did study a larger sample of preservice primary teachers (*N*=117) in Australia than Pickett and Fraser, but they used the *College and University Classroom Environment Inventory* (CUCEI) (Fraser & Treagust, 1986), which was specifically designed for the tertiary level. Pickett and Fraser (2004) conducted an evaluation of a science mentoring program for beginning elementary school teachers in Florida, USA, in terms of learning environment, student achievement and attitudes, and teacher attitudes. Six first-year, second-year and third-year Grade 3—5 teachers were involved in the two-year science mentoring program, and 573 of their elementary school students were also part of the study. This study was significant for three reasons. First, it used a learning environment framework for evaluating a mentoring program. Second, it focused on the learning environment in elementary school science (Grades 3—5) classrooms, an area that had been seldom analyzed before. Third, it focused on the impact of professional development (a mentoring program) on changes in the mentored teachers' teaching behaviors and student outcomes (science achievement and attitudes).

All seven scales on the *actual, personal* form of the WIHIC were used with the Grade 3—5 students, although wording was modified slightly after field testing to make it more appropriate for younger students. All 56 items were initially used in the primary version, but only three response alternatives were provided, namely, Almost Never (1), Sometimes (2), and Almost Always (3). Results of the factor analysis led to the complete elimination of the Involvement scale, as well as removal of a total of five items from the other scales. Reliability for the modified 43-item WIHIC was acceptable for two units of analysis (individual and class mean), and mean correlations of each scale with the other five scales showed the expected slight overlap. An analysis of variance (ANOVA) showed that all six scales differentiated significantly between the classes of the 573 students ($p<0.01$).

Changes in student perceptions of the learning environment, student achievement, and student attitudes towards science were assessed using the subsample of students (*n*=169) in the six teachers' classes that were involved in the science mentoring program. Changes were measured over the eight-month interval between pretesting and posttesting with the WIHIC, a multiple-choice science achievement test, and a Feelings About Science survey that were given to students during the second year of the program. An unusual and interesting finding was that no significant differences were found between pretest and posttest scores for any of the learning environment scales during the mentoring program, but statistically significant differences were found for science achievement ($p<0.01$) and Feelings About Science ($p<0.05$). Interviews with 18 students supported the quantitative findings for the WIHIC and the Feelings About Science survey, and indicated that students did interpret items in ways that were intended by the instrument developers. In terms of outcome-environment associations, another anomaly was that the multiple correlation was statistically significant for science achievement ($R=0.44$, $p<0.01$), but not for Feelings About Science ($R=0.30$).

The WIHIC has also been used at the university level in Indonesia recently. Soerjaningsih et al. (2001) assessed perceptions in computer science classes using four scales from the WIHIC, one scale from the *College and University Classroom Environment Inventory* (CUCEI) (Fraser & Treagust, 1986), and a modified version of the TOSRA. They found "that the association between students' perceptions of the learning environment and their course achievement score is statistically not significant, while association with their Grade Point Average (GPA) score and their satisfaction is statistically significant" (Soerjaningsih et al., 2001, in Margianti, 2002, p. 157).

In another Indonesian study (Margianti, Fraser, & Aldridge, 2002) among 2,498 students enrolled in mathematics classes in one of the private universities, a Bahasa version of WIHIC and the Enjoyment of Science Lessons scale modified from the TOSRA were used. Results indicated a strong factorial structure for the translated version of the WIHIC, and internal consistency indices comparable to the original Australian sample (Fraser et al., 1996), but the ability to differentiate between classrooms (ANOVA results) was lower than previous studies. Margianti (2002) suggested this was due to the nature of university classrooms in Indonesia, which could be more uniform than high school classrooms. Additional analyses comparing *actual* and *preferred* learning environments, contrasting male and female perceptions, and investigating associations between learning environment and cognitive and attitudinal outcomes generally replicated previous studies.

2.5.2 Cross-National Studies with WIHIC

Another hallmark of the learning environments field is a set of cross-national studies that identify interesting cultural differences and/or similarities in psychosocial perceptions. Aldridge et al. (1999) and Aldridge and Fraser (2002) investigated science classroom environments in Taiwan and Australia using multiple research methods. A sample of 1,081 Grade 8 and 9 general science students in Western Australia and 1,879 Grade 7—9 biology and physics students in Taiwan were used to replicate previous research using a 70-item version of the WIHIC, but also to explore causal factors associated with perceptions of the learning environment. By observing and interviewing a subsample of Taiwanese and Australian students and teachers, the authors were able to better understand socio-cultural influences and differences in each country. The study also involved the writing of narrative stories (Carter, 1993; Clandinin & Connelly, 1994) by the researchers, followed by interpretive commentaries that provided a second layer of representation (Geelan, 1997 in Aldridge et al., 1999; Polkinghorne, 1995).

The results of Aldridge et al.'s principal components factor analysis led to the revised 56-item version of the WIHIC (eight items in each of seven scales) that is now widely used in current studies. Factor loadings, internal consistency reliabilities, and the analysis of variance (ANOVA) results for class membership differences are reported in Chapter 4—Quantitative Results, where I also make comparisons between my findings and the Australian and Taiwanese results. Aldridge et al. found that Australian students consistently perceived their learning environments more favorably than did Taiwanese students. Statistically significant differences ($p<0.05$) were found for the WIHIC scales of Involvement, Investigation, Task Orientation, Cooperation and Equity. Interestingly, however, Taiwanese students had more positive attitudes towards science as assessed by the Enjoyment of Science Lessons scale from the TOSRA ($p<0.01$).

In terms of the qualitative data analysis, Aldridge et al. found through student interviews that students interpreted items in ways that were reasonably consistent with other students within the same country. Interviews also generated likely explanations for statistically significant differences between the two countries as assessed by the WIHIC.

Another cross-national study that used the WIHIC involved comparisons between Australia and Indonesia (Adolphe et al., 2003). In this study, researchers assessed junior secondary science students' perceptions of the classroom environment and their attitudes towards science.

Not all cross-national studies have involved Asian countries. For example, Dorman (2003) validated the WIHIC using a sample of 3,980 high school mathematics students from Australia, the UK and Canada. Dorman's novel contribution was that he used confirmatory factor analysis within a structural equation modeling framework to confirm the international applicability and validity of the WIHIC. Results of Dorman's factor analysis, and reliability and discriminant analyses, are also reported in Chapter 4—Quantitative Results, where I again make comparisons with my study's results. In addition to validating the WIHIC, Dorman demonstrated the invariance of the factor structure of the WIHIC across the three countries, grade levels (Grades 8, 10 and 12), and gender. Noteworthy conclusions made by Dorman include that: (1) a ceiling effect might exist for some WIHIC scales (Student Cohesiveness, Task Orientation, Cooperation and Equity), (2) scale reliability and discriminant validity indices were not reduced by any appreciable amount when six items per scale were used rather than the usual eight, (3) the WIHIC can be used with confidence in a wide range of Western countries, and (4) additional validation of the WIHIC in different educational cultures (e.g., Middle Eastern, South and Central America) was recommended.

2.5.3 Studies Involving WIHIC with Secondary Science Students

In addition to the studies conducted at the university level and the cross-national studies, several other studies involving use of the *What Is Happening In this Class?* with secondary science students are noteworthy. Moss and Fraser (2002) used learning environment assessments to guide improvements in the teaching and learning of biology in 18 Grade 9 and 10 classes (*N*=364) in North Carolina, USA. Their method replicated previous research aimed at improving classroom learning environments (Fisher, Fraser, & Bassett, 1995; Fraser & Fisher, 1986; Sinclair & Fraser, 2002; Thorp et al., 1994; Yarrow et al., 1997). Section 2.3.1.3—My Class Inventory (MCI) reviewed Fraser and Fisher's (1986) classic study (i.e., involving a five-step approach in order to make improvements) on this type of learning environments research. Yarrow et al.'s (1997) study also used the five-step approach with

117 preservice primary teachers aimed at improving the environment of their university teacher education classes, and their own classroom environments during practice teaching. Yarrow et al. used the CUCEI for their study. Sinclair and Fraser's (2002) study included ten middle school teachers' participation in action research techniques, involving the use of feedback on perceived and preferred classroom environment as assessed by their newly-developed *Elementary and Middle School Inventory of Classroom Environment.* Changes in classroom climate did occur in both of these studies, supporting the efficacy of the five-step approach employed by Fraser and Fisher (1986) and others.

In addition to trying to improve the teaching and learning of biology, Moss and Fraser (2002) also validated a shorter version of the WIHIC (six items in each of seven scales), looked at differences in the perceptions of boys and girls and of black and nonblack students, and investigated associations between learning environment scales and scores on a statewide biology examination and attitude scales. During the intervention period (Step 3 of the environmental change approach), improvements to selected classroom environment scales were made that had been found to be empirically linked with better academic achievement and attitudes. The researchers found also that males rated their biology classes as having significantly more Involvement and Investigation than the girls ($p<0.05$), while girls perceived significantly more Cooperation ($p<0.01$). There were no statistically significant differences for black versus nonblack students. As with other studies, associations between attitudes and learning environment were stronger than associations between achievement and learning environment. Whereas every scale on the WIHIC was significantly associated with attitudes according to simple correlation analyses, only Student Cohesiveness was significantly correlated ($p<0.01$) with achievement, when using the class mean as the unit of analysis. Multiple regression analyses revealed significant outcome-environment associations for attitudes for both levels of analysis, but only at the individual level for achievement. The standardized regression coefficients showed that only Investigation was a significant independent predictor at both levels of analysis for attitudes, whereas Student Cohesiveness was the strongest independent predictor of achievement.

Taylor and Fraser (2004) conducted the only known study of anxiety among high school students in relation to perceptions of the learning environment and attitudes towards mathematics. Taylor and Fraser sampled 745 mathematics students in Grades 9—12 from four Southern Californian schools. In addition to validating the WIHIC, two scales assessing mathematics anxiety and two scales from the TOSRA modified for mathematics were used to investigate learning environment-attitude and learning environment-anxiety associations. They also examined gender differences in perceptions of the learning environment, mathematics anxiety, and attitudes towards mathematics. Results from the factor analysis and reliability testing confirmed that the WIHIC is a valid and reliable instrument. In terms of gender differences, statistically significant results were found for the WIHIC scales of Student Cohesiveness, Task Orientation, Cooperation, and Equity, with girls perceiving these dimensions of the learning environment more favorably than boys. Again, this replicates considerable previous research (Margianti et al., 2002; Moss & Fraser, 2002), although the authors considered it surprising that girls perceived a higher level of equity in their mathematics classrooms. Research focused on issues of gender equity and equality have reported in the past that girls in high school mathematics classrooms do not feel that they are being treated equally (Levine, 1995; Meece, 1981; Tobias, 1978). Taylor and Fraser point out, however, that there could be a contextual difference in how the word 'equity' is being used in the two fields. Learning environments research tends to place equity in the affective domain, while mathematics education places it in the cognitive domain. Lastly, the researchers found no gender differences for attitudes towards mathematics or mathematics anxiety.

Wallace, Venville, and Chou (2002) used the WIHIC to investigate eighth grade students' perceptions of science classroom environments in a high school in Western Australia. In addition to having all students complete the 70-item questionnaire, the researchers also conducted interviews with four students and the science teacher to probe their understandings of four WIHIC dimensions (Teacher Support, Involvement, Cooperation, and Equity). The main finding in this study was that interviews revealed how students and the teacher did not always share understandings of some of the questionnaire items (e.g., students sometimes guessed at intended meanings). The authors concluded that "learning environments are not the same for the individuals who attend the same classroom" (p. 151), and that the complex nature of learning environments warrants a combination of research methods.

Like the *Science Laboratory Environment Inventory*, the *What Is Happening In this Class?* has been very popular in Asian countries. For example, because the Brunei government was concerned with improving the teaching and learning of science in primary and secondary schools, various researchers have used the WIHIC to gather data in science classrooms. Riah and Fraser (1998) used a modified version of the WIHIC to investigate perceptions in chemistry theory classes among 644 students in 23 government secondary schools. Riah and Fraser found that girls perceived the chemistry environment more favorably than boys, and that the WIHIC scales of Teacher Support, Involvement, and Task Orientation were positively correlated with attitudinal and cognitive outcomes. Khine (2002) also used the WIHIC and two scales from the TOSRA with 1,188 secondary science students in 10 government schools in Brunei. Khine also found that females perceived their science learning environments more favorably than males. In particular, females perceived significantly higher levels of Task Orientation, Cooperation, and Equity. Khine reported that all the WIHIC scales were significantly associated with the Enjoyment of Science Lessons scale on the TOSRA.

As described in Section 2.4.3—Laboratory Learning Environments in Asia, learning environments research has a solid base in Korea, with the WIHIC becoming popular in recent years. Kim et al. (2000) used the WIHIC with 543 eighth grade science students to validate the Korean version of the instrument, explore associations between learning environment and attitude, and uncover any gender-related differences in students' perceptions. Again, the WIHIC was cross-validated and positive relationships were found between learning environment and attitudes. One unusual finding was that boys (rather than girls as in previous studies) perceived their science learning environments more favorably and had more positive attitudes towards science.

2.5.4 Assessing Technology-Rich Learning Environments with WIHIC

Although learning environment studies that have involved university students and secondary science students are the most relevant for my study's population of prospective elementary teachers, recent work assessing technology-rich learning environments and the use of laptop computers in science classrooms also warrant mention. Such studies reveal the flexibility and adaptability of the learning environments field to respond to contemporary educational trends. The course investigated in this study also makes extensive use of laptop computers, the Internet, a database, and software application programs in order to improve prospective elementary teachers' technology competency.

Aldridge et al. (2002) used the WIHIC (along with several new scales) to assess 1,035 senior high school students' perceptions of their actual and preferred learning environments in outcomes-based, technology-rich settings across a number of different subjects, in Perth, Western Australia. They also examined: associations between learning environment and four dependent variables (academic achievement, attitude towards the subject, attitude towards computer use, and academic efficacy); differences between males and females and students enrolled in different courses; and the effect of an outcomes-based curriculum and information communications technology (ICT) in enriching classrooms within an innovative new school.

All seven eight-item scales from the WIHIC were used for this study along with the Differentiation scale from the *Individualized Classroom Environment Questionnaire* (Fraser, 1990), and two new scales called Computer Usage and Young Adult Ethos. Aldridge et al. (2002) renamed the modified instrument the *Technology-Rich Outcomes-Focused Learning Environment Inventory* (TROFLEI). In addition, the researchers used three attitude scales called Attitude to Subject (from the TOSRA), Attitude to Computer Usage (Newhouse, 2001), and Student Academic Efficacy (Jinks & Morgan, 1999). In total, 80 items comprised the entire questionnaire.

Results from this study replicated past research, with the WIHIC again being found to be valid and reliable, especially in terms of a strong factorial structure. By adding new scales that assess outcomes-focused, ICT-rich learning environments, as well as the attitude scales, the new instrument effectively provided data on how to maximize educational outcomes in schools that are becoming increasingly interested in an outcomes-based teaching and learning philosophy, and in technology-enhanced classrooms.

In conjunction with the study described above, Aldridge, Fraser, Murray, Combes, Proctor, and Knapton (2002) used a case-study approach to investigate the learning environment, teaching strategies and implementation of a Grade 11 online nuclear physics program at the same school in Perth. Two physics classes were compared, one that had the course online and one that did not. Observations, interviews and discussions with students and teachers led to narrative stories and interpretive commentaries. Quantitative data were again gathered using the TROFLEI. The researchers "found that students perceived more opportunities in terms of differentiation (to work at their own speed and with work that suits their ability and interests) during the online course than in their regular physics class" (Aldridge et al., 2002,

p. 2). The teacher who taught the online course was also thought to be more supportive, and encouraged cooperation and collaboration between students.

Educators in Canada are also experiencing increasing pressure to incorporate information technology into schools, together with increasing interest in evaluating the effects of this technology on students (Raaflaub & Fraser, 2003). Across four schools in Ontario, Canada, Raaflaub and Fraser (2003) surveyed 1,170 Grade 7—12 mathematics and science students and investigated students' perceptions of learning environments in which laptop computers were used. The WIHIC was used along with one additional learning environment scale regarding computer usage and two attitude scales. In addition to validating the questionnaire, the researchers compared perceptions of actual and preferred learning environments, male and female students, and science and mathematics classes, explored learning environment-attitude associations and, finally, used a case-study approach to identify factors which influence the classroom environment. The case-study was based on one science classroom that was found to have the most positive learning environment. Class observations, interviews with the teacher and students, teacher and student journals, and narrative stories (Carter, 1993; Clandinin & Connelly, 1994) were completed.

Results of Raaflaub and Fraser's (2003) study in Canada indicated strong support for the factorial validity of the eight scales of the modified WIHIC and the two attitude scales, high alpha reliabilities for all scales, large effect sizes for actual-preferred differences, and science classes with statistically significantly higher scores than mathematics classes for Investigation and the two attitude scales. A mix of male-female differences were found across a combination of learning environment and attitude scales as well. For example, pronounced gender differences were found in mathematics classes (females had noticeably higher scores for *preferred* Student Cohesiveness, *actual* Teacher Support and *actual* Equity). Raaflaub and Fraser also found that the level of Computer Usage (the new learning environment scale) was the strongest predictor of attitudes to both subjects and to computers, while the WIHIC scales of Teacher Support, Investigation, and Equity were relatively strong predictors of attitudes towards mathematics and science. Lastly, the one eighth-grade, web-based science class that was selected for the case study proved anomalous because little difference was observed between the students' *actual* and *preferred* scores on all WIHIC scales. Through qualitative data analysis, likely explanations were generated for this result. For example, the laboratory classroom had desks arranged in pods of four to allow same-sex groupings with friends, peer tutoring, cooperation, and cohesiveness.

In another study, Zandvliet and Fraser (2004) compared the psychosocial environments in high school classrooms in Western Canada and Australia in which information technologies have been embraced. A unique focus that Zandvliet and Fraser took was to investigate how networked computer workstations have been physically implemented, and how these can impact and interact with student satisfaction. Like many of the studies already reviewed in this chapter, Zandvliet and Fraser also combined quantitative and qualitative data-collection approaches in order to provide a rich, contextual description of technology-enhanced learning environments in the two countries. Specifically, Zandvliet and Fraser used the five WIHIC scales of Student Cohesiveness, Involvement, Autonomy/Independence, Task Orientation and Cooperation with 1,404 high school students (Grade 10—12) and conducted four case studies in each country. They found that the Internet medium is mainly being used to assist with projects, research and individualized assignments. Although students and teachers largely felt positive about their computerized learning environments, several concerns were expressed regarding room layout, workstation height, temperature, and air quality. Zandvliet and Fraser also found that Canadian settings exhibited slightly more teacher-student interactions than the Australian settings, and that both teachers and students in both countries preferred a 'peripheral' layout for the computers. With regard to the learning environment as assessed by the WIHIC, the researchers noted that both students and teachers perceived Autonomy/Independence as low and that mean scale scores for both countries were comparable with the exception of Involvement and Satisfaction, which were both higher in the Australian sample. Lastly, Zandvliet and Fraser found stronger associations between Satisfaction and the learning environment scales, than between Satisfaction and the physical (ergonomic) measures.

2.5.5 Emerging Learning Environments Research with WIHIC in South Africa

A burgeoning interest in learning environment research has been seen in South Africa over the last few years (Fisher & Fraser, 2003). At the Third International Conference on Science, Mathematics and Technology Education held in South Africa in January 2003, 168 people from 16 different countries attended the conference. Several of the learning environment studies presented at this conference are reviewed in the following paragraphs.

Two South African studies used the WIHIC with primary mathematics students (Ntuli et al., 2003) and with junior high science students (Seopa et al., 2003). Seopa et al.'s study involved 2,638 eighth-grade science learners from 50 schools. The researchers used four scales from the WIHIC (Involvement, Investigation, Cooperation, and Equity), one scale from the *Individualized Classroom Environment Questionnaire*, one scale from the *Constructivist Learning Environment Survey*, and one new scale specifically developed in response to the government's outcomes-based educational philosophy. The resulting questionnaire, in personal actual and preferred forms, was translated into North Sotho (or Sepedi) and then back-translated into English, although items were presented to students in both North Sotho and English. Associations between learning environment and attitudes and science achievement were explored. The factorial structure of the WIHIC scales in the new outcomes-based instrument was fair. The average factor loading for Cooperation was 0.40, for example, and Investigation and Involvement came together to suggest that Grade 8 science students in this sample regarded Involvement and Investigation in similar ways. The researchers concluded that "teachers wishing to improve the learning environment should consider providing more Cooperation, Equity, Personal Relevance, and Responsibility for Own Learning, and less Differentiation" (Seopa et al., 2003, p. 11). Lastly, South African students preferred a more favorable learning environment than the one that they were actually experiencing. This replicates past research in Western primary and secondary schools (Fraser, 1998c). An unusual finding was that no statistically significant differences were found between males and females with regard to actual and preferred learning environments, attitudes towards science, or science achievement.

Ntuli et al.'s (2003) study involved 1,077 primary school mathematics students (Grades 4—7) in 31 classes in which their teachers were attending a distance education course. As with many other learning environment studies, this study also involved the modification and validation of the WIHIC, an investigation of associations between learning environment and attitudes, and a comparison of students' actual and preferred perceptions of the learning environment. Because the study involved primary-age children, the Investigation scale was considered inappropriate and was therefore omitted. Also, the number of items was reduced to 36 (six scales with six items in each), and a simplified three-point response scale consisting of *Almost Never, Sometimes* and *Almost Always* was used. An additional purpose of the study was to examine the extent to which feedback, based on primary students' perceptions on the WIHIC-Primary, could guide the 31 teachers' improvement of their classroom learning environments, in a similar vein as described in earlier studies (Fraser & Fisher, 1986; Moss & Fraser, 2002; Sinclair & Fraser, 2002; Yarrow et al., 1997). Three teachers were selected as case studies and five students from each of the teachers' classes were interviewed at the beginning, middle and end of the 12-week intervention period. When the 31 teachers reviewed their students' actual and preferred scores, they decided to focus solely on improving the Involvement scale. During the intervention period, teachers implemented various strategies in their classrooms in order to improve perceptions of Involvement. At the end of the 12 weeks, the actual form of the WIHIC-Primary was again given to the students and comparisons were made with the pretest data. Based on classroom observations and interviews with the teachers and their students, three narrative stories were written followed by an interpretive commentary, as was done in the Taiwanese and Australian study (Aldridge & Fraser, 2000; Aldridge et al., 1999). Results indicated that some, but not all, of the 31 teachers were able to use the feedback from the WIHIC-Primary to provide students with more opportunities to work in small groups, discuss their ideas and understandings with each other, and to solve problems on their own. Two of the case-study teachers were able to close the gap between actual and preferred scores after the intervention period by using fewer didactic teaching methods, and by being persistent and flexible in finding ways to involve students in their learning.

Sections 2.2 to 2.5 reviewed background information related to the learning environments field, and discussed the conceptualization, development, and application of nine of the most important classroom learning environment instruments. A more thorough review was provided for the SLEI and WIHIC because I extracted scales from these two questionnaires for my study with 525 prospective elementary teachers enrolled in an innovative science course. In many of the studies reviewed, associations between the learning environment and the student outcome of attitudes were also explored. The following section expands and elaborates upon this area of research by examining attitudes towards science and their link with the learning environment.

2.6 Attitudes Towards Science and Their Link with the Learning Environment

In addition to assessing the prospective elementary teachers' perceptions of the learning environment, I also measured attitudes towards science. This was accomplished by using the scale, Enjoyment of Science Lessons, from the *Test of Science-Related Attitudes*—TOSRA (Fraser, 1981). The following three subsections, first, describe the TOSRA including its conceptualization and validation, second, review in greater detail studies that investigated associations between the classroom learning environment and attitudes and, third, review additional studies that have specifically investigated attitudes towards science among elementary teachers.

2.6.1 Test of Science-Related Attitudes (TOSRA)

The *Test of Science-Related Attitudes* (Fraser, 1981) is based on Klopfer's (1971) classification scheme for 'attitudes towards science'. The scheme was developed because of the multiple interpretations and semantic problems associated with the term 'attitudes towards science' in the science education community. Klopfer's scheme distinguishes between six conceptually-different categories of attitudinal aims, and all six are represented in TOSRA.

Fraser's original TOSRA consists of five scales (covering five of Klopfer's six categories) and was validated with 1,323 seventh grade students in Melbourne, Australia (Fraser, 1977a, 1977b). The five scales are called Social Implications of Science, Attitude to Scientific Inquiry, Adoption of Scientific Attitudes, Enjoyment of Science Lessons, and Leisure Interest in Science. The response options are based on Likert's response scale consisting of *Strongly Disagree, Disagree, Not Sure, Agree* and *Strongly Agree.* Approximately half of the items are reverse-scored. Later, the scales of Normality of Scientists and Career Interest in Science were added (now covering all six of Klopfer's categories), and each of the seven scales had 10 items. This version was field tested in Sydney with 1,337 junior high school students in four grade levels (Grades 7, 8, 9 and 10).

Based on the field testing of the seven-scale TOSRA, internal reliability was very good across all grade levels, with an average Cronbach alpha coefficient of 0.82 for all scales.

TOSRA scale discriminant validity indices were fairly low, with the mean correlation of a scale with other scales being 0.33 (Fraser, 1981). Cross-validation data were obtained when the TOSRA was administered to additional students in Australia, as well as to students in the United States. The Australian sample totaled 2,593 junior and senior high school students, while the sample from Philadelphia, Pennsylvania, consisted of 546 ninth grade students (Fraser, 1981). Fraser reported that the cross-validation results were favorable as well, and that: “These results are important, not only because they provide additional support for the validity of TOSRA for use with Australian students, but also because they support the cross-cultural validity of TOSRA for use in the United States” (p. 6).

From the beginning of its rigorous field testing during the late 1970s with thousands of secondary science students, the TOSRA continues to be widely used 25 years later. Minor modifications have been made to TOSRA for some studies, however, including a reduction of items from ten to eight, rewording of items, and the use of the five-point response options of *Almost Never, Seldom, Sometimes, Often* and *Almost Always* to correspond with response alternatives used in several learning environment instruments. The TOSRA is frequently used in learning environments research to investigate associations between classroom learning environment and the student outcome of attitudes. This area of research has the strongest tradition in past studies (Fraser, 1998a). Researchers have used anywhere from one scale to all seven scales from the TOSRA in their studies. The following section reviews several prominent studies that have used the TOSRA to explore associations between the classroom learning environment and attitudes, with a particular focus on attitudes towards science.

2.6.2 Associations Between the Classroom Learning Environment and Attitudes Towards Science

An early study that looked at the relationship between perceived levels of classroom individualization and science-related attitudes was Fraser and Butt’s study (1982). The sample consisted of 712 junior high (Grades 7—9) school students in 30 classes from Australia, who completed the ICEQ and all seven scales from the TOSRA (10 items per scale). Students responded to TOSRA both as a pretest near the beginning of the school year and again as a posttest towards the end of the same school year, and responded to ICEQ at mid-year.

Using multiple regression analyses, Fraser and Butt found that student perceptions on the set of five individualization dimensions (Personalization, Participation, Independence, Investigation, and Differentiation) accounted for a significant increment in the variance in end-of-year attitude scores, beyond that attributable to corresponding beginning-of-year attitude scores, for four of the TOSRA scales (Social Implications of Science, Enjoyment of Science Lessons, Leisure Interest in Science, Career Interest in Science). Furthermore, all significant associations between an individualization dimension and an attitudinal outcome were found to be in the positive direction.

In a similar design to the above study, Fraser and Fisher (1982b) used both the ICEQ and the CES with six scales from TOSRA to investigate the relationships between classroom environment perceptions and attitudes towards science. The sample consisted of 1,083 junior high school students in 116 science classrooms in Tasmania. Whereas the previous study used only the class mean as the unit of analysis, Fraser and Fisher’s study used both the student and the class mean as units of analysis. Overall, Fraser and Fisher also found sizable relationships between students’ attitudinal outcomes and perceptions of the classroom environment. Their findings suggest that attitudes to the Social Implications of Science can be promoted in classes with greater Participation and Order and Organization, and Leisure Interest in Science can be enhanced in classes with greater Involvement, Order and Organization, and Innovation. In addition, by estimating the strength of the environment-attitude relationships for two units of analysis, it was shown that effect sizes were greater when the class was employed as the unit of analysis than when the individual was used.

Another noteworthy study that modified the TOSRA for use with chemistry students was a large-scale study conducted in Singapore (Wong & Fraser, 1994,1996; Wong et al., 1997). The sample consisted of 1,592 tenth grade chemistry students and 56 teachers. The study had several aims, one of them being to investigate associations between students’ perceptions of chemistry laboratory environments, as assessed by the *Science Laboratory Environment Inventory*—SLEI, and attitudes towards chemistry. Wong and colleagues used three of the seven TOSRA scales and renamed them slightly for the context of chemistry laboratory environments (Attitude to Scientific Inquiry in Chemistry, Adoption of Scientific Attitudes in

Chemistry, and Enjoyment of Chemistry Lessons). Simple correlational, multiple regression, and canonical analyses were conducted to investigate environment-attitude associations, using both the individual and class mean as units of analysis. Results of the simple correlational analyses indicated that, generally, all laboratory environment scales (Student Cohesiveness, Open-Endedness, Integration, Rule Clarity, and Material Environment) were significantly associated with each attitude scale. In particular, Integration and Rule Clarity were strong and consistent correlates of the attitude scales for both units of analysis. A particularly interesting finding was that all the significant simple correlations were positive except for one case in which the greater levels of perceived Open-Endedness were associated with lower scores on Attitude to Scientific Inquiry in Chemistry. Multiple correlational analyses revealed statistically significant ($p<0.05$) associations for all three attitude scales for both units of analysis. An examination of the regression weights and the results of the canonical analyses confirmed the findings from the simple correlational analyses.

Using the same sample, Wong et al. (1997) reanalyzed the Singaporean data using Hierarchical Linear Modeling (HLM). HLM is considered a more rigorous procedure for investigating associations between variables, and overcomes the problem of 'nested' data or aggregation bias and misestimated precision. This was important in the Singaporean study with the chemistry students because there was significant variation at both the student and class levels for the learning environment measures, due to differences in both the classes and the students' perceptions of their classes. Furthermore, there were variations at both the student and class levels for the students' attitudes towards chemistry. Data were examined at two levels (student and class), and hence a two-level HLM was formulated. Overall, 12 cases of significant attitude-environment associations were found using HLM, compared to 15 for the multiple regression analyses. There were negligible differences between the results of the multiple regression analyses and the HLM analyses for two out of three attitude measures. The HLM findings confirmed that Integration was a strong and consistent predictor of all three attitudinal outcomes at the student level. However, a conspicuous difference occurred with Enjoyment of Chemistry Lessons in that the reliability of estimates was greater and the intra-class correlation was larger. Specifically, when class means were investigated for their effect on Enjoyment of Chemistry Lessons, there appeared to be significant differences in Open-Endedness and Rule Clarity (i.e., these two environment measures positively influenced student enjoyment of chemistry lessons for some classes). This HLM finding is in sharp contrast to the multiple regression analysis that suggested Open-Endedness was significantly negatively associated with the attitude scale called Attitude to Scientific Inquiry in Chemistry.

Another study that used the SLEI and the TOSRA was conducted in Australia, USA, and several South Pacific Islands involving 2,819 tenth and eleventh grade science students. Giddings and Waldrip (1996) compared science laboratory classrooms and students' attitudes towards science across 12 countries. Although they did not investigate associations between environment and attitudes, this study was interesting because it assessed attitudes towards science by using the aggregate score from responses of 17 items from the TOSRA. Giddings and Waldrip found that students from all the South Pacific countries had similar attitudes towards science, and that they were more favorable than those of the Australian and USA sample. In addition, females had a less favorable attitude towards science than did the males.

Several studies investigating associations between classroom environment and more than one outcome measure have made valuable contributions to the learning environments field. One notable study (Henderson et al., 2000) explored associations between students' perceptions of their biology teachers' interpersonal behavior and their laboratory learning environments and their attitudinal, achievement, and performance outcomes. A sample of 489 students from 28 senior biology classes in Tasmania completed the QTI, the SLEI, two scales modified from the TOSRA, a written examination, and practical laboratory tests. Henderson et al. found that associations with students' perceptions of the learning environment were stronger for the attitudinal outcomes than for the cognitive or practical skills outcomes.

During the last five years, it seems as if the number of studies investigating associations between the classroom learning environment and attitudes towards science have accelerated. Additional studies that have used scales from the TOSRA to investigate environment-attitude associations replicate the general trends described in the studies reviewed in this section (Adolphe et al., 2003; Aldridge & Fraser, 2000, 2003; Aldridge et al., 1999, 2002; Kim & Fraser, 2000; Pickett & Fraser, 2004; Raaflaub & Fraser, 2003; Seopa et al., 2003; Soto-Rodriquez & Fraser, 2004; Taylor & Fraser, 2004). Several Asian studies have modified the TOSRA for use in subject areas other than the science disciplines as well (e.g., mathematics and geography) (Fraser & Chionh, 2000; Goh et al., 1995; Margianti et al., 2002).

2.6.3 Studies of Attitudes Towards Science Among Prospective and Preservice Elementary Teachers

In addition to the many studies that have examined associations between the learning environment and attitudes towards science, other science education researchers have focused on attitudes among science students at various grade levels, including attitudes among prospective and preservice elementary teachers. This last section in this chapter reviews studies that are relevant to my work—some of them shed light on the origin and complex nature of attitudes towards science, and on the many challenges faced by science teacher educators who want to improve attitudes so that future elementary students will enjoy science. The studies are not all doom and gloom, however, as several studies have many positive things to say about future elementary teachers and their attitudes towards science and science teaching.

Attitudes to science, at all levels of science learning, have been a consistent concern in science education for nearly 40 years (Osborne, Driver, & Simon, 1998). For prospective elementary teachers, the ramifications of a negative attitude towards science are far-reaching. Koballa and Crawley (1985) reported that prospective elementary teachers bring their positive or negative attitudes towards science to their first teaching assignment, and then inadvertently pass these attitudes on to their own students. In an earlier study, Shrigley (1974) found that, if inservice elementary teachers did not like science, then their students tended not to like science. In addition, a strong link has been found between teachers' attitudes and confidence/comfort levels for teaching science and the amount and quality of science that actually gets taught in elementary classrooms (Jarrett, 1999; Lucas & Dooley, 1982; McDevitt, Heikkenen, Alcorn, Ambrosio, & Gardner, 1993; Pedersen & McCurdy 1992; Stefanich & Kelsey, 1989). Negative teacher attitudes lead to little science instruction and/or poor instructional strategies (Riggs, 1989; Sunal, 1980a, 1980b; Wilson & Scharmann, 1994, in Scharmann & Orth Hampton, 1995). The 2000 National Survey of Science and Mathematics Education, conducted by Horizon Research, reported that, on average, only 31 minutes per day are spent teaching and learning science in Grade 4-6 classrooms in the USA (Weiss, Banilower, McMahon, & Smith, 2001).

The connection between elementary teachers' attitudes towards science and students' attitudes is obvious. It, therefore, seems logical to begin the work of developing positive attitudes during prospective elementary teachers' preparation programs. Lee and Krapfl (2002) noted that, during the 1990s, many elementary science teacher preparation programs underwent reform, with a major objective of improving prospective and preservice elementary teachers' attitudes about science and teaching science. Lee and Krapfl point out that reforming entire programs is far more effective than changing only one or two courses. They feel that it is difficult to change future elementary teachers' conceptions of teaching science because of the stability of culturally-derived beliefs about teaching, and because of so many years of passive listening, regurgitation, and verification activities in their own schooling (Fosnot, 1989; Tilgner, 1990). Other researchers have found that even inservice workshops for elementary teachers have only short-term effects, with teachers reverting to their original attitudes with the passage of time (Gabel & Rubba, 1979).

However, if we want any hope of breaking the cycle of ineffective elementary science instruction and improving attitudes towards science, we must begin with our future teachers. They must be exposed to science courses at the post-secondary level that embrace nontraditional science teaching and learning. Prospective elementary teachers who learn science in a different way "will be encultured with a different model of teaching" (Lee & Krapfl, 2002, p. 247) and teach their own future students in a different (and better) way. One study in Australia did compare attitudes towards science and science teaching in a traditional science course compared to a nontraditional course. Ginns and Foster's (1983) study in Brisbane, Australia with 471 prospective elementary teachers involved comparing the attitudes of students randomly assigned to two science courses designed around two different conditions: one course offered a choice of inquiry-based topics and took place in an unstructured learning environment; the second course was lecture and laboratory based. Attitudes were assessed using the *Science Teacher Attitude Scales–STAS* (Moore, 1973; Moore & Sutman, 1970). The researchers found that: "Males obtained higher positive gain scores for attitudes under the lecture approach, while females in this condition obtained the lowest of the four gain scores. In the topic approach [inquiry-based], the females achieved a greater positive change in attitudes than the males" (Ginns & Foster, 1983, p. 281). They concluded that the inquiry-based topic approach was more suitable for effective positive changes in attitudes to science and science teaching among female students, suggesting this was because of females' preferred learning style of personal involvement.

Stepans and McCormack (1985) looked at 72 prospective elementary teachers' attitudes towards science teaching at the University of Wyoming. In their study, they compared attitudes of 'younger' versus 'older' students, and analyzed correlations between the number of college/university courses and attitudes. Using an attitude instrument developed by Cummings (1969), their results indicated that 'older' students had more favorable attitudes towards science and scientists than 'younger' students (although they did not define what they meant by 'young' or 'old'), and that there was no relationship between the number of science courses completed and attitudes towards science and science teaching. Specifically, they found that the more biology and/or chemistry courses completed, the more likely students were to rate science as difficult to understand, or to say that "science is boring" (Stepans & McCormack, 1985, p. 7). This confirms Shrigley's (1974) finding for inservice elementary teachers of a low correlation between science knowledge and teachers' attitudes toward science.

Talsma (1996) analyzed attitudes towards science and science teaching in 56 autobiographical essays of prospective elementary teachers at a medium-sized mid-western university in the United States. Autobiographies in Talsma's study revealed a variety of factors that reflected both positive and negative attitudes. On the positive side were discussions of active, hands-on experiences, many experiments and investigations, and enthusiastic and interested teachers and parents. On the negative side, prospective elementary teachers wrote about reading textbooks, doing worksheets, content that was not relevant to everyday life, boredom, confusion and frustration, and teachers who had no interest in the subject or disrespected students.

Palmer (2002) pointed out that the extent of negative attitudes towards science among preservice teachers could be exaggerated. Some studies have found that the majority of students in classes for elementary education majors have either neutral or positive attitudes about science teaching (Jarrett, 1999; Young & Kellogg, 1993). In Palmer's study of a science content/methods course in Australia, he interviewed four preservice elementary teachers who said their attitude had changed from negative to positive (i.e., attitude exchange had occurred) by the end of the course. During the interviews, Palmer identified the causes of attitude exchange among the four preservice teachers. The causes were of three main types: (1) personal attributes of the tutor (enthusiasm, confidence), (2) specific teaching strategies (clear explanations that used simple language, hands-on activities, encouraging students' questions, modeling of classroom practice suitable for elementary students), and (3) external validation (evidence that the teaching techniques worked with children in real elementary classrooms). Palmer emphasized that college and university science instructors can change students' minds about science, and that this can be done by utilizing a range of simple techniques that any teacher can learn to use.

Cobern and Loving (2002) investigated preservice elementary teachers' views of science by using their new instrument called "Thinking About Science." The instrument addresses the broad relationship of science to nine important areas of society and culture (e.g., science and the environment; science, race, and gender) and has 35 items with the Likert response options of *Strongly Agree, Agree, Uncertain, Disagree,* and *Strongly Disagree.* Almost 700 preservice elementary teachers enrolled in a science methods course over a five-year period comprised the sample that validated Thinking About Science. Cobern and Loving found that preservice elementary teachers discriminate with respect to the nine different categories of science and socio-cultural aspects described in the instrument, but they are not antiscience. Preservice teachers begin their profession with many of their own ideas about science and, although these ideas are "retained as a core philosophy" (Gustafson & Rowell, 1995, p. 600), the researchers felt the preservice elementary teachers are moving in a direction consistent with science education reforms.

Lastly, it must be acknowledged that successful reforms of undergraduate science content courses designed specifically for prospective elementary teachers do occur (Crowther, 1997; Friedrichsen, 2001; Lee & Krapfl, 2002; McLoughlin & Dana, 1999; Poole & Kidder, 1996; Stepans, McClurg, & Beiswenger, 1995). The key finding common in most studies of these innovative science courses is that a connection is purposively made between science content and elementary teaching pedagogy. Prospective elementary teachers in such courses participate in relevant hands-on inquiry-based activities that they can eventually use in their own future elementary classrooms.

2. 7 Summary of Chapter

My study's primary research area encompasses the classroom learning environments field. Hence this chapter reviewed in considerable detail literature related to this field. The chapter was divided into five major sections. A section entitled Background to the Learning Environments Field provided a descriptive definition for learning environments and then overviewed the history and development of the classroom learning environments field. It also discussed salient issues that learning environment researchers must consider in their studies such as private and consensual beta press, units of analysis, short versus long forms, actual versus preferred forms, and types of research areas that can be studied. Twelve different areas of learning environments research have been identified. Studies that explore associations between the learning environment and various student outcomes, such as attitudes and cognitive achievement, have proven to be the most popular over the last three decades.

The second section reviewed seven of nine historically-important instruments that are used to assess classroom learning environments. These instruments include the *Learning Environment Inventory*—LEI, *Classroom Environment Scale*—CES, *My Class Inventory*—MCI, *Individualized Classroom Environment Questionnaire*—ICEQ, *College and University Classroom Environment Inventory*—CUCEI, and the *Questionnaire on Teacher Interaction*—QTI. Several noteworthy studies that used each of these instruments were also briefly mentioned. Because I used scales from the *Science Laboratory Environment Inventory*—SLEI and *What Is Happening In this Class?*—WIHIC in my study, the third and fourth sections were devoted to the conceptualization, development, and application of the SLEI and WIHIC. Both the SLEI and WIHIC are powerful assessment tools and, when combined with qualitative research approaches, they can help science educators to better understand the complexities, nuances, and contextual layers of science classrooms. Overall, the number, variety, ease of use, and versatility of the nine instruments is a hallmark of the learning environments field. The instruments can serve many purposes from an individual teacher's action research in a single classroom to evaluating science reform programs across an entire school district, state or country. They have been used in over a dozen countries, on four continents, with tens of thousands of students at various grade levels, in a variety of subject areas, and even translated into such languages as Malay, Mandarin, Korean, Indonesian, and Spanish.

The last major section in this chapter reviewed studies related to attitudes towards science and their link with the classroom learning environment. The student outcome of attitude is frequently studied alongside psychosocial perceptions of the classroom learning environment.

I, too, wanted to investigate the attitudes of the 525 female prospective elementary teachers in my sample, both before and after the course evaluated in my study, A Process Approach to Science—SCED 401. This last section reviewed the development and validation of the *Test of Science-Related Attitudes*—TOSRA, from which I extracted one scale called Enjoyment of Science Lessons. Despite being developed 25 years ago, the TOSRA's rigorous initial field-testing has withstood the test of time. Many of its scales can be easily modified and used in other subject areas such as mathematics (Margianti et al., 2002; Raaflaub & Fraser, 2003; Taylor & Fraser, 2004). Lastly, I reviewed studies that looked at associations between the learning environment and attitudes, and additional studies specifically focusing on attitudes towards science among prospective and preservice elementary teachers.

A secondary area of research that my study covers is the nature of science. All five of my research questions include assessing prospective elementary teachers' understandings of the nature of science. Because the nature of science has been a perennial goal of science education for close to 100 years (Lederman, 1992), the course, A Process Approach to Science, has as a goal of improving students' understandings of the nature of science and what actual scientists do. Therefore, it was appropriate in evaluating the effectiveness and impact of the course to include instruments that measure understandings of the nature of science. However, because the field of the nature of science is as vast as the learning environments field, Chapter 3 provides a separate literature review on studies related to the nature of science.

Chapter 3

THE NATURE OF SCIENCE: REVIEW OF RELATED LITERATURE

3.1 Introduction and Overview

"When the nature of science is misconceived, inevitably the influence of science on practical affairs is also misconceived" (Bauer, 1994, p. 103). Understanding the nature of science has been an educational goal for close to 100 years (Lederman, 1992), yet misconceptions about what science is, how scientists go about doing their work, and the relevance of science to our everyday lives continue to permeate our science classrooms from elementary to tertiary levels of education, including classes for future teachers.

The science course investigated in this study—*A Process Approach to Science* (SCED 401)—is a required course for prospective elementary teachers. Although prospective elementary teachers at California State University, Long Beach, have taken at least three science courses prior to beginning SCED 401, the majority of students hold many misconceptions about science. Consequently, two of the primary goals of SCED 401 are to improve students' understandings of the nature of science and what scientists actually do in their work, and to develop students' ability to identify, define, and solve problems like scientists do. Accomplishing these goals is a challenge for all SCED 401 instructors. I have attempted to reach these goals by introducing an 'intervention' into my classes that consists of providing students with real scientific data of chick growth rates for Antarctic seabirds that they can use during their experimental design project. I also have the wildlife biologist who collected the seabird data participate in my class by visiting occasionally and guiding students' progress during the project. The wildlife biologist (who has a joint faculty appointment in both Biological Sciences and Science Education) and I felt that the 'intervention' would improve students' perceptions of the laboratory classroom environment and attitudes towards science, although we felt that the intervention's greatest impact would be on students' understandings of the nature of science. Therefore, along with the learning environment and attitude scales, an instrument was needed to assess understandings of the nature of science before and after SCED 401.

A review of literature related to the nature of science was necessary because about half of the items in the overall questionnaire were from the *Nature of Scientific Knowledge Survey* (NSKS) (Rubba & Anderson, 1978) that I chose to use for my study. In addition, I also used several open-ended items from *Views of Nature Of Science* (VNOS) (Lederman et al., 2002). This review also was necessary because of the role of the intervention in achieving the SCED 401 goal of improving students' understandings of the nature of science. This chapter is structured in a manner similar to Chapter 2 that discusses the field of classroom learning environments. Section 3.2 defines and explains what is meant by the term 'nature of science'. Section 3.3 provides an overview of the nature of science as an educational goal. Section 3.4 describes the two instruments that I used in my study to assess understandings of the nature of science. Subsections in Section 3.4 discuss the development and validation of the NSKS and the VNOS, as well as studies that utilized the two instruments. Although much of the review focuses on the nature of science field in general, I continually make finer adjustments in order to lead back to my study's participants (i.e., female prospective elementary teachers). Consequently, Section 3.5 discusses three issues and trends related to teaching and learning about the nature of science, with a focus on studies involving teachers. Section 3.6 reviews specific studies that investigated elementary teachers' conceptions of the nature of science, first between 1950 and 1990, and then between 1991 and the present. Lastly, Section 3.7 provides a summary of the chapter.

3.2 What *is* Nature of Science?

It is generally agreed that the nature of science encompasses the field of epistemology, an area of study that involves how scientific knowledge is generated and the character of science itself (Lederman, 1992; Lederman et al., 2002; Schwartz, Lederman, & Crawford, 2004). The nature of science is concerned with how actual science is done and how scientists go about doing their work. Other science education researchers refer to the nature of science simply as the 'social studies of science' (Aikenhead & Ryan, 1992) or the 'history and philosophy of science (HPS)' (Matthews, 1994), although the nature of science does not necessarily have to include history. Advocates for nature of science study point out that the science children learn in schools from their science teachers is often not an accurate portrayal of real science occurring in laboratories or field settings, or even of how science is used in other professional jobs outside purely scientific careers.

McComas (1998) provides a good overall description of the nature of science in the following paragraph:

> The nature of science is a fertile hybrid arena which blends aspects of various social studies of science including the history, sociology, and philosophy of science combined with research from the cognitive sciences such as psychology into a rich description of what science is, how it works, how scientists operate as a social group and how society itself both directs and reacts to scientific endeavours. Through multiple lenses, the nature of science describes how science functions.
>
> (McComas, 1998, pp. 4-5)

Despite being a goal of science education efforts during the past 100 years (Abd-El-Khalick, Bell, & Lederman, 1998; Duschl, 1990; Meichtry, 1992), philosophers, historians, sociologists of science, and science educators still disagree on a specific definition of nature of science. Consequently, in many nature of science studies, one will see 'nature of science' instead of the more stylistically appropriate '*the* nature of science'. Using 'nature of science' implicitly implies that there is no one single, agreed upon definition (Abd-El-Khalick, 2001, 1998; Alters, 1997; Lederman, 1992; Lederman et al., 2002; Schwartz et al., 2004; Loving, 1997; Turner & Sullenger, 1999). "Similar to scientific knowledge, conceptions of nature of science are tentative and dynamic" (Lederman et al., 2002, p. 499). This fluid character of nature of science is apparent when one examines various science education documents and instruments used to describe and assess understandings of the nature of science. Contemporary, postmodern views of the nature of science include several 'tenets' or 'aspects' that are believed to be important in understanding the nature of science. Figure 3.1 lists 14 of the most common tenets/aspects of the nature of science that were compiled from eight international science standards documents.

Several of these objectives can be seen in instruments that aim to assess understandings of the nature of science. *Views of Nature Of Science–VNOS* (Lederman et al., 2002) (discussed in Section 3.4.2) covers 10 of the 14 objectives, while the *Nature of Scientific Knowledge Survey–NSKS* (Rubba & Anderson, 1978), that I also used in my study (discussed in Section 3.4.1), includes only three of the objectives. Therefore, to answer 'what is the nature of science', one must first ask 'whose nature of science?' (Alters, 1997; Loving, 1997; Turner & Sullenger, 1999). Researchers point out that nature of science questionnaires tend to reflect the biases, beliefs, and personal interpretations of their developers (Cotham & Smith, 1981;

Lederman, Wade, & Bell, 1998) to a greater extent than other instruments in less contentious fields.

Nature of Science Objectives

1. Scientific knowledge while durable, has a tentative character.
2. Scientific knowledge relies heavily, but not entirely, on observation, experimental evidence, rational arguments, and skepticism.
3. There is no one way to do science (therefore, there is no universal step-by-step scientific method).
4. Science is an attempt to explain natural phenomena.
5. Laws and theories serve different roles in science. Therefore students should note that theories do not become laws even with additional evidence.
6. People from all cultures contribute to science.
7. New knowledge must be reported clearly and openly.
8. Scientists require accurate record keeping, peer review and replicability.
9. Observations are theory-laden.
10. Scientists are creative.
11. The history of science reveals both an evolutionary and revolutionary character.
12. Science is part of social and cultural traditions.
13. Science and technology impact each other.
14. Scientific ideas are affected by their social and historical milieu.

Figure 3.1. A consensus view of the nature of science objectives extracted from eight international science standards documents (McComas, 1998, pp. 6-7)

3.3 Overview of the Nature of Science as an Educational Goal

It is worthwhile to take a brief glimpse at the early educators who were the first to recognize and articulate the importance of learning about the nature of science. Ernst Mach (1838—1916), philosopher, physicist, and science educator, is believed to be the first person to promote an understanding of what we now describe as ‘nature of science’ (Matthews, 1994). Mach believed that “scientific theory is an intellectual construction for economizing thought, that science is fallible; it does not provide absolute truths, that science is a historically conditioned intellectual activity, and that scientific theory can only be understood if its historical development is understood” (Mathews, 1994, p. 98). Here we can recognize commonalities with McComas’ consensus objectives listed in Figure 3.1 (namely, objectives 1, 11, and 14). Mach, in particular, advocated that:

> Science teachers should follow the historical order of development of a subject, address the philosophical questions that science entails and which gave rise to science, and show that just as individual ideas can be improved, so also scientific ideas have constantly been, and will continue to be, overhauled and improved. (Matthews, 1994, p. 98)

Mach was also one of the first educators to promote 'thought experiments' because he believed that, if students exercised their creativity and imagination during science, they were building a connection between the humanities and the sciences (Matthews, 1994). Interestingly, both the *Nature of Scientific Knowledge Survey* (Rubba & Anderson, 1978) and *Views of Nature Of Science* (Lederman et al., 2002) include considerations of creativity and imagination in scientific work.

In an extensive review of 40 years of qualitative and quantitative studies on students' and teachers' conceptions of the nature of science, Lederman (1992) traced the history of the nature of science emphases to 1907 when the Central Association of Science and Mathematics Teachers stated that processes of science and increased emphasis on the scientific method were important in science teaching. In 1916, John Dewey stated that understanding scientific method is more important than the acquisition of scientific knowledge (Hodson, 1985). Such statements appear to only indirectly imply that learning about the nature of science is important. In 1960, an explicit reference to the nature of science was made by the National Society for the Study of Education when they said: "Science is more than a collection of isolated and assorted facts…a student should learn something about the character of scientific knowledge, how it has been developed, and how it is used" (Hurd, 1960, p. 34). Today, learning and understanding the 'history and nature of science' is listed among eight science content standards for kindergarten to twelfth grade students in the highly-respected National Science Education Standards—NSES (National Research Council, 1996). The NSES states that "students should develop an understanding of what science is, what science is not, what science can and cannot do, and how science contributes to culture" (p. 21). Clearly, the importance of understanding the nature of science and its central role in the objectives for science education has been recognized for a long time.

Lederman (1992) stated in his review that research related to the nature of science falls into five related, but distinct, categories: (1) students' conceptions of the nature of science, (2) teachers' conceptions of the nature of science, (3) assessment of nature of science curricula and interventions, (4) relationships between teachers' nature of science conceptions, classroom practice, and students' nature of science conceptions, and (5) development and validation of nature of science assessment instruments (both quantitative and qualitative). My study includes aspects of categories (2) and (3). Sections 3.6.1 and 3.6.2 review studies related to elementary teachers' understandings of the nature of science as these are most aligned with my study. One curriculum development project is worth mentioning, nevertheless, due to its links to both the nature of science and learning environments research. Harvard Project Physics was an innovative curriculum that included a historical and philosophical examination of physics knowledge generation using a case-study approach. It also sparked the development of the first learning environment instrument. Walberg and Anderson (1968) developed the *Learning Environment Inventory* (LEI) during their evaluation of Harvard Project Physics. The LEI led the way for the emerging learning environments field, and subsequent development of many additional instruments for assessing learning environments in unique settings and for varied purposes.

When should the topic of the nature of science be addressed during an elementary teacher education program? McComas (1998) explains that the nature of science can be taught during a science methods course (the most common approach if taught at all), during undergraduate science content courses, during a stand-alone nature of science course at either the undergraduate or graduate level, or as authentic experiences with an actual scientist (e.g., a summer internship working with a scientist). If the nature of science is taught in a science methods course, it is often sandwiched between the pedagogical and content issues that must be covered in such a course. Quite understandably, prospective teachers are primarily concerned with practical, survival teaching techniques and want to know 'what I can do in my classroom tomorrow'. In addition, learning about the nature of science in a methods course (i.e., out of context or nonintegrated) could impede the translation of prospective teachers' acquired nature of science understandings into their instructional practice. Research has indicated that such translation is, at best, limited and mediated by a host of constraining factors (Abd-El-Khalick et al., 1998; Aquirere, Haggerty, & Linder, 1990; Bell, Lederman, & Abd-El-Khalick, 2000; Brickhouse & Bodner, 1992). Several researchers feel that it is more effective to learn about the nature of science in the context of or integrated within a science content course (Abd-El-Khalick, 2001).

Typically, science content courses are taught by staff from science departments, and rarely is there any mention of the nature of science. The course investigated in this study, *A Process Approach to Science–SCED 401,* is unusual in that it is taught by science educators who have considerable K–12 science teaching experience (average of 10 years of experience), and who value teaching the nature of science. However, other examples of science educators teaching science content courses, and including nature of science, do exist (Abd-El-Khalick, 2001).

Other nature of science researchers feel that intern or apprenticeship programs involving scientists in classroom inquiry, field work or laboratory activities are most effective for understanding the nature of science (Bell, Blair, Crawford, & Lederman, 2003; Schwartz et al., 2004; Schwartz, Westerlund, Koke, Garcia, & Taylor, 2003). (Section 3.6.3 discusses authentic scientific inquiry and the nature of science.) The intervention introduced into my classes of SCED 401, in which I enlisted the help of a wildlife biologist in order to make an experimental design project more authentic, appears to be the first attempt in the science education community to provide authentic scientific inquiry in an elementary teacher education program. The intervention involved using the wildlife biologist's actual data of four species of Antarctic seabird chicks and their growth rates for four anatomical features that were measured over two seasons of field work. Interestingly, Pomeroy (1993) found that prospective elementary teachers are more open-minded to the nature of science tenets, and less traditional in their view of the nature of science compared to secondary science teachers and even scientists. Pomeroy feels that this is a result of "scientists' and secondary science teachers' deep initiation into the norms of the scientific community" (p. 269).

3.4 Questionnaires for Assessing Understanding of the Nature of Science

During the past 40 years, more than 20 standardized, convergent paper-and-pencil instruments have been developed to assess understanding of the nature of science. Recently, the standardized instruments have been criticized on the basis of their questionable validity (i.e., the extent to which they actually assess what they purport to measure) (Gall, Borg, & Gall, 1996; Lederman et al., 1998). For example, nature of science items on questionnaires tend to be more ambiguous than learning environment items, and this results in a greater chance of incongruence between what the developers mean and what the respondents perceive and interpret. Also, as mentioned earlier, nature of science instruments reflect their developers' nature of science views and biases (Lederman et al., 1998) and, because they are forced-choice instruments, they can impose the developers' views on respondents. Thus "the views that ended up being ascribed to respondents were more likely an artifact of the instrument in use than a faithful representation of the respondents' conceptions of the nature of science" (Lederman et al., 2002, p. 502). Consequently, throughout the 1990s, there were developed several free-choice or open-ended response questionnaires, some with the recommendation of conducting interviews with respondents to verify and clarify answers. Nature of science research moved away from quantitative studies and embraced highly interpretive qualitative studies involving small sample sizes.

The following sections discuss the two questionnaires that I used in my study–*Nature of Scientific Knowledge Survey (NSKS)* (Rubba & Anderson, 1978), that uses a Likert response format, and *Views of Nature Of Science (VNOS)* (Lederman et al., 2002), an open-ended response questionnaire. Studies related to elementary teachers' understandings of the nature of science that used these instruments are described in Sections 3.6.1 and 3.6.2.

3.4.1 Nature of Scientific Knowledge Survey (NSKS)

3.4.1.1 Development and Validation of NSKS

The NSKS was developed by Rubba and Anderson (1978) and based on earlier work by Showalter (1974) at the Center for Unified Science Education at Ohio State University. Showalter synthesized 15 years of science education literature relating to the concept of 'scientific literacy' and produced a seven-dimension definition of scientific literacy. In his first dimension Showalter stated that a "scientifically literate person understands the nature of scientific knowledge" (Rubba & Anderson, 1978, p. 450). Rubba and Anderson then set out to develop, field test, and validate an instrument to assess secondary school students' understandings of scientific knowledge. The result was the *Nature of Scientific Knowledge Survey—NSKS.*

The NSKS has 48 items that are randomly arranged. Respondents choose from a five-point Likert scale consisting of *Strongly Disagree, Disagree, Neutral, Agree,* and *Strongly Agree,* with half of the items reverse-scored. The NSKS includes six scales, namely, Amoral (scientific knowledge itself cannot be judged good or bad), Creative (scientific knowledge is partially a product of human creative imagination), Developmental (scientific knowledge is tentative), Parsimonious (scientific knowledge attempts to achieve simplicity of explanation as opposed to complexity), Testable (scientific knowledge is capable of empirical test), and Unified (the specialized sciences contribute to an interrelated network of laws, theories, and concepts). A detailed description of each scale along with a sample item can be seen in Table 4.3 in Chapter 4–Research Methods. The Creative, Developmental, and Testable scales correspond to McComas' objectives #10, #1, and #2 in Table 3.1, respectively. The scales of Amoral, Parsimonious, and Unified, however, are not covered in the consensus list of international science standards documents. Some researchers have subsequently modified the NSKS (Meichtry, 1992) by eliminating the scales of Amoral and Parsimonious.

Many of the 48 items in the NSKS contain the word 'not', and often pairs of items are identical, except that one item is worded negatively. Lederman et al. (1998) felt that this redundancy could encourage respondents to refer back to their answers on previously, similarly-worded items, resulting in inflated reliability estimates and erroneous acceptance of the instrument's validity (p. 339). An example of several pairs of items that are worded in this fashion are seen below:

Creative Scale:	Scientific laws, theories, and concepts express creativity. Scientific laws, theories, and concepts do **not** express creativity.
Parsimonious Scale:	Scientific knowledge is specific as opposed to comprehensive. Scientific knowledge is comprehensive as opposed to specific.
Developmental Scale:	Scientific knowledge is unchanging. Scientific knowledge is subject to review and change.

However, the reliability of the NSKS was assessed during its development with 595 secondary science students and 354 college students (nonscience majors and philosophy of science students). Coefficient alphas (Nunnally, 1967) ranged from 0.65 to 0.89 for the various classes. Test-retest reliability was also established with 87 high school science students. The Pearson product-moment correlation coefficients between the test and retest, six weeks later, were 0.59 and 0.87, respectively.

Rubba and Anderson (1978) also examined the construct validity of the NSKS by testing an anticipated difference in understandings of the nature of scientific knowledge between two groups of first-year college students. Using an *ex post facto* design, 40 students completing an introductory philosophy of science course were compared to 125 students at the same university completing a biology course for nonscience majors. Using *t*-tests for independent samples, Rubba and Anderson found that the students who had studied philosophy of science had higher mean scores on five of the six NSKS scales (all except Creative), of which four were statistically significant ($p<0.05$ or above).

3.4.1.2 Understandings of the Nature of Science Among Secondary Science Students and Teachers–Studies Between 1950 and 1990

Section 3.7.1 reviews studies on elementary teachers' understandings of nature of science between 1950 and 1990. The focus is on elementary teachers because this aligns with the participants in my study. During this 40-year time frame, there was one study that used the *Nature of Scientific Knowledge Survey* with high school biology teachers (Lederman & Druger, 1985; Lederman & Zeidler, 1987) in conjunction with qualitative methods. The study is noteworthy because it is the only published research that investigated relationships between *classroom variables* (some that describe the learning environment) and understandings of nature of science. The studies of Lederman and Druger and of Lederman and Ziedler used the same sample of teachers and students and the same methodology. During analysis, however, the focus was slightly different, and each study came to a different conclusion. Specifically, the sample involved 18 tenth grade biology teachers and 409 of their students. The purpose of the Lederman and Ziedler (1987) study was to test the validity of the assumption that a teacher's conception of nature of science directly influences his/her classroom behavior. The NSKS was used in a pretest-posttest design with both the teachers and the students.

Qualitative methods in both studies included observations that were conducted three times in each teacher's class. After "systematic pairwise qualitative comparisons" (Lederman & Ziedler, 1987, p. 724) were made with 18 sets of field notes, 44 classroom variables were generated that appeared to discriminate among the behaviors of the 18 teachers. Six of the teachers' "content-specific characteristics" identified as classroom variables included "Amoral, Creativity, Developmental, Parsimony, Testable, and Unified" (Lederman & Ziedler, 1987, p. 730), corresponding to the scales on the NSKS. Examples of variables that were identified as teachers' "non-instructional characteristics/attitude" included "demeanor and impersonal", while "classroom atmosphere" variables included "down time, low anxiety, and rapport" (p. 730). Relationships were determined between the classroom variables and teachers' conceptions of the nature of scientific knowledge by ranking the teachers based on the mean of the pretest and posttest scores on the NSKS (only 4 'high' and 4 'low' teachers were identified). The ability of each of the 44 classroom variables to statistically discriminate between 'high' and 'low' teachers was assessed by using a non-directional binomial test ($p<0.05$) (Kerlinger, 1965). The authors reported that only one (down time) out of 44 classroom variables significantly differentiated between the 'high' and 'low' teachers, and this did not support the assumption that a teacher's classroom behavior is directly influenced by his/her conceptions of the nature of science.

In the Lederman and Druger (1985) study, the researchers only used the overall score and the Developmental scale from the NSKS to evaluate relationships between classroom variables and students' conceptions of nature of science. They reported that "the data do not support the contention that a teacher's conception of the nature of science, in and of itself, is significantly correlated with changes in his/her students' conceptions of science" (p. 655). They concluded, therefore, that "specific teacher behaviors and other classroom variables must play an important role in determining any changes in conceptions of students" (p. 657). Lederman and Druger (1985) identified 'generally successful' classrooms in which students exhibited the greatest conceptual changes as having "active participation, frequent, inquiry-oriented questioning and problem-solving with little emphasis on rote memorization, teachers who were more supportive, pleasant, and humorous, and who used anecdotes to aid instruction and establish rapport" (pp. 657—661).

3.4.1.3 Understandings of the Nature of Science Among Secondary Science Students and Teachers–Studies Between 1991 and the Present

In addition to the study described in the previous section, several other studies were conducted after 1990 that involved secondary science students and teachers, using the *Nature of Scientific Knowledge Survey*. This section provides a brief overview of these studies.

The most recent study that used the NSKS was an exploratory case study conducted in Florida with Grade 9—12 students (N=38). Walker and Zeidler (2003) also used the *Views on Science-Technology-Society* (Aikenhead & Ryan, 1992; Aikenhead, Ryan, & Fleming,

1987) and *Views of Nature Of Science* (Lederman et al., 2002). However, the NSKS was only administered as a pretest to provide a baseline measure of students' conceptions of nature of science. The purpose of the study was to investigate how students' engagement in an Internet-based unit on a current scientific controversy (genetically-modified food) influenced their understanding of the nature of science and, in turn, informed their decision-making on the issue. Although it is not clear how the researchers used or compared the NSKS baseline data, they concluded: "As measured by the NSKS and supported by online nature of science interview questions, the majority of the students' answers reflected adequate conceptions of the tentative, creative, subjective, and social aspects of science" (p. 26).

Lonsbury and Ellis (2002) used the NSKS with 107 Grade 9 biology students in Kansas using a quasi-experimental, pretest-posttest design. The purpose of their study was to examine the effectiveness of using historical figures and events in science (Gregor Mendel and early genetics) to learn about nature of science. They concluded that incorporating science history into a biology course has the potential to increase students' knowledge related to nature of science, without detracting from their acquisition of content knowledge needed for standardized examinations. They stated that science history, in particular, is effective in helping students to realize that scientific knowledge is testable rather than absolute.

In 2000, Chun and Oliver investigated 31 middle school teachers' changes in self-efficacy and knowledge of nature of science, after participating in three summer workshops in Georgia. In comparing pretest and posttest mean scores on the NSKS, the researchers found that the teachers' mean scores increased on the posttest, but that the differences were not statistically significant. Many of the teachers already held 'adequate' understandings, such as that scientific knowledge must be Testable and that scientific knowledge is Developmental or tentative. The NSKS scales of Creative and Unified showed the greatest difference between mean pretest and posttest scores, but again the differences were not statistically significant. The researchers concluded that the middle school science teachers' beliefs were not easily changed, and that the initial level of understanding of nature of science can affect the degree of change in teacher beliefs after an intervention.

The last study to be reviewed that examined understandings of nature of science among secondary science students using the NSKS was conducted by Meichtry (1992). Meichtry investigated the effects of the first-year field test of the Biological Science Curriculum Study (BSCS, 1990), an innovative middle school science program, on students' understandings of four aspects of nature of science. Meichtry modified the NSKS by using only four scales in her study—Creative, Developmental, Testable, and Unified. Validity was determined statistically by conducting a factor analysis of the pretest results. A total of 1,004 sixth, seventh, and eighth grade students received the BSCS curriculum, while 693 students in another comparable school were taught using a more traditional middle school science curriculum. Meichtry found that students in both groups, prior to and following the treatment, possessed less than 'adequate' (defined as a score less than 24 for any one scale; maximum score is 40) understandings of all four aspects measured with the modified NSKS. After the course, students taught with the BSCS approach did not appear to score markedly different from students in the control group. Specifically, when pretest and posttest scores were compared for the two groups, it was found that students taught with the BSCS approach had statistically significantly lower scores on the posttest on the Developmental and Testable scales. Students in the control-group science program had statistically significant lower scores for Creative. These results are not surprising in that the mere use of a science program designed to develop students' understandings of nature of science (implicitly), is no guarantee that these understandings will in fact develop.

3.4.2 Views of Nature Of Science–Form C (VNOS–C)

Views of Nature Of Science–Form C (Lederman et al., 2002) is an open-ended response questionnaire based on a Kuhnian (1962) philosophy of science, and developed with a postmodern interpretive framework in mind. Its aim is to reveal participants' views on various aspects of nature of science for the purpose of informing the teaching and learning of NOS. The developers state the VNOS should not be used to label learners' views as adequate or inadequate, or to sum their nature of science understandings into a numerical score. The VNOS is based on eight 'aspects' of nature of science that are considered less contentious, attainable, and relevant to the daily lives of K–16 students and teachers (Abd-El-Khalick et al., 1998; Lederman et al., 1992; Smith, Lederman, Bell, McComas, & Clough, 1997). These aspects and their corresponding objectives from Figure 3.1 include the ideas that scientific knowledge is:

1. Tentative *(McComas'#1)*
2. Empirically-based *(McComas' #2)*
3. Subjective or theory-laden *(McComas' #9)*
4. The product of both observations and inferences *(partly McComas' #2 again)*
5. Dependent on creativity and imagination *(McComas' #10)*
6. Socially and culturally embedded *(McComas' #6, #12, and #14)*
7. Based on a foundation of theories and laws *(McComas' #4 and #5)*
8. Not derived from a universal, recipe-like method for doing science *(McComas' #3)*.

The developers stress that these aspects are interrelated and cannot be considered apart from the others, and that there is not a one-to-one correspondence between an item on the questionnaire and a target nature of science aspect listed above (Lederman et al., 2002; Schwartz et al., 2004). The items consist of 10 open-ended questions (see Figure 4.1 in Chapter 4 for the four items that I chose to use in my study), administered in a pretest-posttest design. Developers also emphatically say that interviews must be conducted with a subsample (15-20%) in order to probe respondents' views further and clarify or expand upon understandings. Abd-El-Khalick (1998) developed a specific interview protocol to use with certain responses to each of the items, and details of the protocol can be found in Lederman et al.'s (2002) study that helped to validate the VNOS–C. Validity was established by comparing participants' nature of science profiles generated from their written responses with their corresponding interview transcripts (Abd-El-Khalick, 1998, 2001). Comparisons indicated congruence between the two formats.

Researchers using the VNOS categorize participants' responses as either naïve, informed, or in no category (despite their earlier claim that VNOS should not be used to label respondents' views) (Lederman et al., 2002, p. 517). These ratings were determined during an examination of the construct validity of an earlier VNOS instrument (VNOS–B with 7 items) (Bell, 1999). Similar to how construct validity was determined for the *Nature of Scientific Knowledge Survey,* Bell believed that respondents with expert or informed understandings of the nature of science would respond differently from people with naïve understandings. The expert group consisted of nine individuals with doctoral degrees in science education, or history or philosophy of science, while the novice group comprised nine individuals with doctoral degrees in fields such as American literature, history, and education. Data analyses indicated that the expert group's responses reflected current/informed views of the nature of science at a rate nearly three times higher than those of the novice group (Bell, 1999; Lederman et al., 2002).

The VNOS has been used with secondary science and university-level students, and with preservice and inservice secondary teachers in numerous studies during the past five years (Abd-El-Khalick, 1998, 2001; Abd-El-Khalick et al., 1998; Abd-El-Khalick & Lederman, 2000; Bell et al., 2000, 2003; Dekkers, 2003; Kenyon & Chiappetta, 2003; Khishfe & Abd-El-Khalick, 2002; Khishfe & Lederman, 2004; Kim & Lederman, 2004; Lederman, 1999; Lederman, Schwartz, Abd-El-Khalick, & Bell, 2001; Matkins, Bell, Irving, & McNall, 2002; Schwartz & Lederman, 2002; Schwartz et al., 2004; Schwartz et al., 2003; Sunal, Sunal, Sundberg, Odell, & Bland, 2002). Overall, the three forms of the VNOS (A–4 items; B–7 items; C–10 items) have been administered to about 2,000 participants across four continents, coupled with about 500 individual interviews (Lederman et al., 2002). Recent research has focused on individual classroom interventions aimed at enhancing nature of science understandings (e.g., introducing metacognitive strategies such as concept mapping, scientist-teacher and scientist-student collaborations and internships, and conceptual change and learning-cycle teaching strategies).

3.4.3 Other Questionnaires

Although most of the current nature of science research is conducted using *Views of Nature Of Science,* the science education community is calling for the development of a new, up-to-date standardized convergent instrument appropriate for large samples (Good et al., 2000). VNOS is only suitable for small sample sizes and, although it can provide *meaningful* assessment (Lederman et al., 2002) and be more valid than Likert scale questionnaires, there is still value in describing and evaluating learners' understandings of a challenging and complex concept like nature of science. Lederman et al. (1998) critiqued many nature of science instruments and acknowledged that eight (in addition to the NSKS and the modified NSKS) were valid and reliable measures of the nature of science. Table 3.1 provides, for each of these instruments, the names of their developers and a brief description of the format of the questionnaire.

Table 3.1
Additional Standardized and Convergent Instruments for Assessing Understanding of the Nature of Science

Name	Developers/Year	Brief Description of Format
Test on Understanding Science (TOUS)	Cooley & Klopfer, 1961	Four-alternative, 60-item multiple-choice test that produces three scale scores, and an overall score.
Wisconsin Inventory of Science Processes (WISP)	Scientific Literacy Research Center, 1967	93 statements in which respondents evaluate as accurate, inaccurate or not understood. Only an overall score is obtained.
Science Process Inventory (SPI)	Welch, 1966	135-item forced-choice inventory (agree/disagree), with no scales.
Nature of Science Scale (NOSS)	Kimball, 1968	29-items requiring an *agree, disagree,* or *neutral* response. Determines whether science teachers have the same view of science as scientists. Lacks scales.
Nature of Science Test (NOST)	Billeh & Hasan, 1975	60 multiple-choice items based on four components of nature of science. No scales exist, and only an overall score is obtained.
Views of Science Test (VOST)	Hillis, 1975	Only measures 'tentativeness' of science. Includes 40 items that respondents decide are either tentative or absolute, using a five-option Likert scale.
Conceptions of Scientific Theories Test (COST)	Cotham & Smith, 1981	Attitude inventory consisting of 40 Likert scale items (with four options) and four scales.
Views on Science-Technology-Society (VOSTS)	Aikenhead, Ryan, & Fleming, 1987	Consists of a 'pool' of 114 multiple-choice items (some with as many as 10 options and always including *I don't understand* and *I don't know enough about this subject to make a choice*). Does not produce a numerical score, as respondents choose from alternative viewpoints.

Lederman, Wade, & Bell (1998, pp. 334—341)

3.5 Issues and Trends Related to Teaching and Learning About the Nature of Science

Research on the nature of science over the past four decades has provided at least four consistent findings with regard to teachers' conceptions of the nature of science, regardless of the instrument used in the investigation:

1. Science teachers appear to have inadequate or 'naïve' conceptions of the nature of science.

> 2. Efforts to improve teachers' conceptions of the nature of science have achieved some success when either historical aspects of scientific knowledge or explicit instruction on the nature of science have been included.
> 3. Academic background variables have not been significantly related to teachers' conceptions of the nature of science.
> 4. The relationship between teachers' conceptions of nature of science and classroom practice is not clear, but the difficulties in transferring an understanding of the nature of science to teaching nature of science is mediated by various instructional and situational concerns.
>
> (Lederman et al., 1998, p. 332)

From these findings, three issues are of particular importance to my study and these are discussed in the following sections. Section 3.6.1 elaborates Lederman et al.'s second point that "efforts to improve teachers' conceptions of the nature of science have achieved some success when…explicit instruction on nature of science have been included". Several studies have compared the effectiveness of an explicit reflective versus an implicit (inquiry) instructional approach, and I discuss the main findings in Section 3.5.1. Section 3.5.2 discusses a fairly new area of nature of science study in which contextualized versus decontextualized approaches to teaching and learning about the nature of science are compared. Another very recent trend in nature of science research is discussed in Section 3.5.3. Researchers are finding that learning about the nature of science is both contextualized *and* authentic when real scientists are involved in working alongside students and teachers. This approach has been called *authentic scientific inquiry* and it was also used as an intervention in my six SCED 401 classes.

3.5.1 Explicit Reflective Versus Implicit (Inquiry) Instructional Approaches

Many studies have emphatically stressed that, because nature of science is a complex cognitive concept, it must be taught explicitly and in conjunction with reflective written exercises and/or discussions, irrespective of whether young children, high school students, science majors in college, or prospective, preservice or inservice teachers are learning about the nature of science (Abd-El-Khalick, 2000; Abd-El-Khalick & Akerson, 2004; Akerson, Abd-El-Khalick, & Lederman, 2000; Bianchini & Colburn, 2000; Khishfe & Abd-El-Khalick, 2002; Khishfe & Lederman, 2004; Lederman et al., 2002; Lederman & Lederman, 2004; Kenyon & Chiappetta, 2003; Schwartz et al., 2004). Although the nature of science has been a science education goal for close to 100 years, early studies assumed understandings of the nature of science could be acquired by simply having students (including preservice teachers) engage in hands-on inquiry activities (Atkin, 1966, 1968; Atkin & Karplus, 1962; Carey & Stauss, 1968; Kimball, 1968; Rutherford, 1964). This assumption arose because inquiry has been used to describe both nature of science and a method of science instruction (DeBoer, 1991; Chiappetta, 1997; Rutherford, 1964; Tamir, 1983). Specific topics, issues, or ideas about how scientific knowledge is created, or how scientists go about their work, usually were not explicitly taught in science courses for students at the elementary, secondary, or tertiary levels, or during science methods courses for preservice elementary and secondary teachers.

The *explicit* approach advocates that the nature of science should be planned for instead of being anticipated as a side effect or secondary product of hands-on inquiry (Akindehin, 1988). Doing hands-on inquiry activities with students and preservice teachers is effective for learning about the processes of science but, in order also to develop contemporary understandings of the nature of science, learners must be cognitively engaged and made aware of nature of science aspects. Teaching about the nature of science should be similar to teaching about any other cognitive learning outcome. Explicit teaching approaches include whole-class discussions with a teacher knowledgeable about the nature of science (Bianchini & Colburn, 2000), small-group peer discussions and debates (Cobern & Loving, 1998; Hammrich, 1998), hands-on activities specifically designed to teach about one or more nature of science aspects (Lederman & Abd-El-Khalick, 1998), written exercises and assignments specifically about nature of science aspects, and nature of science lesson plans designed with a learning cycle or conceptual change model in mind (Abd-El-Khalick & Akerson, 2004; Akerson & Abd-El-Khalick, 2004). It is desirable to integrate as many of these approaches as possible into a course.

The key to teaching about the nature of science in an explicit reflective approach is the teacher, whether that teacher is in an elementary classroom with eight-year-olds, or a science teacher educator in a methods course for prospective teachers. Bianchini and Colburn (2000) were both instructors at California State University, Long Beach, and taught the course investigated in my study (*A Process Approach to Science–SCED 401*). Bianchini was the researcher during the study, however, and videotaped 20 hours of Colburn's instruction during SCED 401. Specifically, she videotaped how Colburn conducted guided and open-ended inquiries with the 15 prospective elementary teachers, and what they discussed in group and whole-class deliberations. Bianchini did not use an instrument to assess understandings before, during, or after the course. Rather, she identified aspects of the nature of science addressed during inquiry instruction, and during group and whole-class discussions. The researchers concluded that the teacher plays a pivotal role in initiating discussions of what science is and how scientists work, and that thoroughly and consistently conveying an accurate description of the nature of science is a difficult task for an instructor. One must also keep in mind that Colburn has extensive training in the biological sciences, worked in a laboratory setting, taught high school biology for several years, earned a doctorate in science education, and has a special interest in nature of science. If he found teaching the nature of science a challenge, one must consider how much more challenging it must be for the typical elementary or secondary science teacher.

Closely associated with the argument for teaching nature of science using an explicit, reflective approach is the issue of teaching and learning nature of science *in context* versus in a *decontextualized* fashion. The next section discusses this distinction.

3.5.2 Contextualized Versus Decontextualized Nature of Science

Some researchers argue that explicitly teaching the nature of science, outside a science content course, has only a limited effect on changing and improving understandings of nature of science. Nature of science activities and discussions can appear to be an 'add-on', if not tightly linked to science content (Brickhouse, Dagher, Letts, & Shipman, 2000; Clough, 2003; Clough & Olson, 2001; Driver, Leach, Miller, & Scott, 1996; Khishfe & Abd-El-Khalick, 2002; Ryder, Leach, & Driver, 1999). This view is particularly applicable to science methods courses for both elementary and secondary teachers, in which pedagogical knowledge and skills are emphasized over cognitive outcomes such as nature of science. Beginning teachers are mainly concerned with classroom management and discipline strategies, and not with the philosophical perspectives of science.

In a contextualized approach, the nature of science is interwoven with the content in traditional science courses. In a chemistry course, for example, one can teach the tentative and empirical aspects of the nature of science simultaneously while teaching about the atomic model. In a biology course, the differences between theories, hypotheses, and laws, and between inferences and observations, can be easily addressed during the topic of evolution.

In the past, studies have incorporated nature of science with history of science courses or units (Abd-El-Khalick, 1998; Lonsbury & Ellis, 2002; Solomon, Duveen, Scott, & McCarthy, 1992) and improvements in secondary science students' understandings were found. Abd-El-Khalick and Lederman (2000) assessed the influence of three history of science courses on 166 college students' and 15 preservice secondary science teachers' conceptions of nature of science. Using the VNOS, the researchers found very few and limited changes in participants' views during the courses when the nature of science was not addressed explicitly. However, when the nature of science was explicitly addressed during the course, the history of science courses were relatively more effective in enhancing participants' nature of science views.

Aside from the history of science/nature of science studies mentioned above, most studies investigating explicit attempts to teach the nature of science to prospective and preservice elementary teachers have been undertaken in science methods courses (Akerson et al., 2000; Gess-Newsome, 2002; Shapiro, 1996). Only one study investigated the effect of embedding nature of science instruction in a science content course for preservice elementary teachers (i.e., teaching nature of science in context) (Abd-El-Khalick, 2001). Abd-El-Khalick's study involved 30 female elementary education majors enrolled in a semester-long physics course designed specifically for future elementary teachers at an American university in Lebanon. The female prospective elementary teachers in the study were similar to the participants in my study as the majority of students in both studies had non-scientific streams during high school, an impartial view or dislike of science, and limited success in college science courses. However, in my study, SCED 401 was students' fifth post-secondary science course while, in Abd-El-Khalick's study, the investigated course was the participants' first tertiary science course. Abd-El-Khalick was the teacher-researcher for the course. He used the following approaches to teach the nature of science: (1) five generic hands-on activities that addressed various aspects of the nature of science, (2) content-embedded nature of science activities such as 'Rutherford's Enlarged', a model of the atomic nature of matter and, (3) reflective prompts throughout the course in which nature of science aspects were reinforced during small-group peer discussions, investigations and experiments, and spontaneous whole-class discussions. Abd-El-Khalick found that most participants held 'naïve' conceptions and scientistic views of the six target nature of science aspects at the beginning of the course. After experiencing the explicit reflective content-embedded nature of science instruction, some gains were noted in terms of a more informed view of the nature of science but, at the same time, most participants seemed to have shifted to a 'naïve relativistic' worldview. Also, participants had difficulty transferring their understandings in the context of unfamiliar subject matter that was not covered in the course (e.g., extinction of the dinosaurs) as compared to more familiar subject matter (atomic structure).

A recent strategy to overcome the challenges of learning about the nature of science, whether in a contextualized or decontextualized format, has been to create *authentic scientific inquiry* experiences for students and preservice and inservice teachers. This approach is discussed in the following section.

3.5.3 Authentic Scientific Inquiry and the Nature of Science

Involving scientists in the school classroom has great intuitive appeal. Most science teachers have never worked on a long-term scientific research project in a laboratory or field setting. Understandably, the real world of science is not typically represented in science classrooms (Chinn & Malhotra, 2002; Driver et al., 1996; Roth, 1995; Ryder et al., 1999). Conceivably, teachers have just as much to learn from scientists in the classroom as their students. Several 'science vacation' companies have arisen in recent years to capitalize on this gap in teacher preparation programs, and their 'vacations' are extremely popular (e.g., Earthwatch, Inc.). But innovative researchers and teachers have also taken the initiative to involve willing and education-oriented scientists in sharing the discoveries of science and in conveying a more accurate picture of scientists' work. In addition, science teacher educators have advocated greater collaboration between science educators and scientists in teacher preparation programs at the university level (Briscoe & Prayaga, 2004; Conant, 1963; Schwartz et al., 2004; Sweeney & Paradis, 2002; Tobin, Roth, & Brush, 1995).

Making science learning more like real science has been a common goal among science educators at least since John Dewey (Edelson, 1998). *Authentic scientific inquiry* coupled with nature of science, however, is relatively recent in science education research. Schwartz et al. (2004) attempted to bridge the gap between nature of science and scientific inquiry for 13 preservice secondary science teachers during a summer research internship experience. In addition to the laboratory research component (which amounted to five hours per week over 10 weeks) involving a university scientist for each teacher, the summer course included seminars and reflective journal assignments on the nature of science. Teachers' activities with the scientists varied with each project, but most were considered 'low inquiry' internships because the teachers were not involved in critical decision making. "Their context was authentic but quite peripheral" (Schwartz et al., 2004, p. 618). The teachers were enrolled in a fifth-year Master of Arts in Teaching (MAT) teacher preparation program, and several teachers already had graduate degrees in science. Prior to the summer intern course, the preservice teachers began their MAT program with a specific course on the nature of science that included generic and content-specific activities. All eight 'target' aspects of the nature of science were addressed during this course. At the beginning and at the end of the summer intern course, nature of science views were assessed using *Views of Nature Of Science–Form C* and supported by interviews with participants. Prior to the internship, most teachers articulated, to some degree, an understanding of most of the eight aspects of the nature of science, although the depth of their understandings varied (e.g., mimicry of definitions to elaborate descriptions with examples). Compared to other participants in similar studies, these teachers held few misconceptions, with only four out of the 13 teachers citing naïve views of a particular aspect of the nature of science during their pretest responses. At the completion of the internship, 11 of the 13 teachers (85%) demonstrated enhanced views of the nature of science, with four demonstrating major improvements in one or more aspects. In addition, most of the 11 teachers included supporting examples from their inquiry experience in their posttest responses, and they were able to articulate the connectedness among nature of science aspects. Lastly, the greatest factor influencing the positive changes was *not* the science research experience, but rather the reflective journal writings work (11 out of 13 teachers attributing their advancements to this factor). None of the interns felt that their research experience directly impacted their nature of science views, although the researchers stated that it provided "an authentic context for reflection: a real research setting with which to apply and revise one's knowledge of nature of science" (p. 632).

Bell et al. (2003) found similar results with Grade 10—11 science students who were involved in an eight-week summer apprenticeship program with scientists. The participants were 10 volunteers from a group of 18 high-ability students who agreed to complete a modified version of VNOS–B Form (including six nature of science items and two questions about scientific inquiry). Semistructured exit interviews were conducted with both the students and the laboratory scientists who served as mentors. Although the scientists held strong convictions that their apprentices had learned a great deal about doing scientific work, most of the students' conceptions about key aspects of the nature of science remained virtually unchanged (but their knowledge about the processes of scientific inquiry improved). In the single case for which a student did show significant gains in her nature of science understandings, "epistemic demand and reflection appeared to be crucial components" (p. 487) for her change.

Scientists do science and, although they can create an authentic scientific context for inquiry for high school students or preservice science teachers, the above studies indicate that explicit reflective writing and discussions on key aspects of the nature of science also must be included if substantial improvements in understanding the nature of science are to be made. Other studies have involved students in successful student/teacher-scientist collaborations that aimed to create authentic scientific inquiry experiences, but without an emphasis on improving understandings of nature of science (Barab & Hay, 2001; DiGennaro King & Bruce, 2003; Kesselheim, Graves, Sprague, & Young, 1998; Rahm, Miller, Hartley, & Moore, 2003). My study is timely because it is the first known research to investigate the impact of an intervention that attempted to create an authentic scientific inquiry experience for prospective elementary teachers in a science course. Although the intervention was not based on a full-scale apprenticeship model, the prospective elementary teachers were able to use an extensive database of Antarctic seabird chick growth rates, engage in authentic reasoning in the context of interpreting and graphing existing data, and communicate with the wildlife biologist who collected the data on a personal level. Details of how the invention improved, and did not improve, prospective elementary teachers' understandings of nature of science are discussed in Chapter 5—Quantitative Results and Chapter 6—Qualitative Results.

3.6 Nature of Science Research Related to Prospective Elementary Teachers

Sections 3.4.1 and 3.4.2 described the two instruments that I used in my study—*Nature of Scientific Knowledge Survey* (Rubba & Anderson, 1978) and *Views of Nature Of Science* (Lederman et al., 2002)—and briefly reviewed studies in which the researchers used one of these two instruments with secondary and university-level students and teachers. Although many of the findings and conclusions from these studies are relevant to my study, I wanted to highlight those studies that involved prospective, preservice, or inservice elementary teachers, because my study also involved 525 female prospective elementary teachers enrolled in a capstone science course. The following two sections, therefore, provide an overview of research into elementary teachers' understandings of nature of science. Section 3.6.1 addresses studies between 1950 and 1990, while Section 3.6.2 covers studies conducted after 1990.

3.6.1 Studies of Elementary Teachers' Understandings of the Nature of Science– 1950--1990

To place in perspective the 1950—1990 time frame and the studies that were conducted during this period, it is appropriate to note all the nature of science studies conducted with teachers during these 40 years. Table 3.2 summarizes the nature of science studies involving secondary science teachers and elementary teachers between 1950 and 1990. As can be seen, only two out of 19 published studies involved elementary teachers (Bloom, 1989; Carey & Stauss, 1970a, 1970b).

Carey and Stauss were the first researchers to analyze and attempt to improve prospective elementary teachers' conceptions of the nature of science. They had a large sample size involving 221 students who completed the *Wisconsin Inventory of Science Processes* (WISP–see Table 3.1) (Scientific Literacy Research Center, 1967) during a science methods course using a pretest-posttest design. The researchers found no relationship between the elementary teachers' conceptions of the nature of science as measured by the WISP and academic background variables (number and type of high school science courses, number of college science courses, overall and science grade-point average).

Bloom (1989) was the first researcher to combine qualitative and quantitative methods in studying preservice elementary teachers' conceptions of the nature of science. Bloom assessed 80 elementary teachers (86% female), enrolled in a science methods course, on their understandings of science and how certain contextual variables contribute to this understanding. Bloom used six open-ended questions (the genesis of the *Views of Nature Of Science*) and a 21-item rating scale for his assessment. The open-ended questions asked about scientific knowledge, evolution, and the nature of theories, while the rating scale involved students' prior experiences with science, science teaching, the distinction between evolution and creationism, and the nature of science. Bloom discovered that preservice elementary teachers were confused over the meaning and role of scientific theories, and that personal beliefs affected their understandings of science.

Table 3.2
Summary of Studies on Teachers' Understandings of the Nature of Science from 1950 to 1991

Year of Publication	Author(s)	Sample	Method
1950	Anderson	58 biology & 55 chemistry teachers in Minnesota	Survey—eight questions on scientific method
1961	Behnke	400 biology & 600 physical science teachers	Survey—50 questions on the nature of science, science and society, and the teaching of science
1963	Gruber	314 participants in an NSF-sponsored institute for science teachers	Survey
1963	Miller	733 Grade 7—12 students & 51 biology teachers in Iowa	Compared students & teachers conceptions using the *Test on Understanding Science* (TOUS) (Klopfer & Cooley, 1961)
1967	Schmidt	Grade 9 & 11/12 students & a sample of teachers	Replicated Miller's (1963) study also using the TOUS
1968	Welch & Walberg	162 physics teachers who participated in a summer institute	Pretest/posttest design using the TOUS & *Science Process Inventory* (SPI) (Welch, 1966)
1968	Carey & Stauss	17 prospective secondary science teachers in Georgia	Pretest/posttest design using the *Wisconsin Inventory of Science Processes* (WISP) during a science methods course
1968	Kimball	A sample of professional scientists & science teachers	Compared two groups using his own *Nature of Science Scale* (NOSS) (continued)
1969	Lavach	26 science teachers divided into experimental & control groups	Development of an inservice program on history of science. Pretest/posttest design using the TOUS
1970a	Carey & Stauss	Experienced teachers	Pretest/posttest design using the WISP
1970b	Carey & Stauss*	35 prospective secondary science teachers & 221 prospective elementary teachers	WISP

Con't.

1975	Billeh & Hasan	186 secondary science teachers in Jordan	Development of an inservice program that partly included nature of science. Used their own *Nature of Science Test* (NOST)
1983	Tamir	26 preservice & 24 practicing science teachers	Examined written responses of teachers who were trained in inquiry for understandings of NOS
1985 1987	Lederman & Druger Lederman & Zeidler	18 experienced biology teacher	Used NSKS & classroom observations to identify 44 classroom variables
1989	Koulaidis & Ogborn	12 beginning & 11 preservice science teachers	16-item, multiple-choice questionnaire on the nature of science
1989	Bloom*	80 preservice elementary teachers (86% females) enrolled in three methods courses.	Six open-ended questions on the nature of science involving qualitative analysis & 21-item rating scale
1989	Cobern	21 American preservice science teachers & 32 preservice Nigerian teachers	NOSS used to compare the two groups
1990	Aguirre, Haggerty, & Linder	74 preservice secondary science teachers	11 open-ended questions involving qualitative analysis

*Study involved elementary teachers.

3.6.2 Studies of Elementary Teachers' Understandings of the Nature of Science—1991 to the Present

During the 40-year period between 1950 to 1990, 19 studies of teachers' conceptions of the nature of science were conducted, with only two studies involving elementary teachers (10%). During the next 13.5 years, 20 out of 55 studies (not counting 'position papers') (36%) involved elementary teachers. Clearly, research on teachers' conceptions of the nature of science has accelerated, with more focus recently being given to elementary teachers. Table 3.3 provides a summary of the 20 studies conducted between 1991 and the present.

Of the 20 studies involving prospective, preservice or inservice elementary teachers, the majority (15/20 or 75%) were strictly qualitative studies and, of these, seven used the *Views of Nature Of Science* questionnaire. Only two studies were strictly quantitative studies, with one study using the *Nature of Scientific Knowledge Survey* (Meichtry, 1999). Two additional studies used the NSKS, but one study included an analysis of open-ended journal entries (Gess-Newsome, 2002), while the second used classroom observations of student teaching and artifact analysis (lesson plans, written in-class assignments) (Bright & Yore, 2002). Overall, there were three studies that combined quantitative and qualitative methods to assess understandings of nature of science (Bright & Yore, 2002; Gess-Newsome, 2002; Murcia & Schibeci, 1999).

When reviewing the context of each of the 20 studies, one can see that the majority (11/15 or 73%) of studies involved a science methods course. As discussed in Section 3.6.2, however, this is a *decontextualized* approach to teaching and learning about nature of science. Despite using hands-on activities and reflective discussions that explicitly address specific aspects of nature of science in the course, students probably regard the topic as an 'add-on' or supplement to pedagogical content. Other studies have clearly shown that preservice elementary teachers do not transfer their understandings of nature of science to their teaching practice (Akerson & Abd-El-Khalick, 2003; Bartholomew & Radcliffe, 2004; Bright & Yore, 2002; Mellado, 1997).

Only three of the studies assessed understandings of nature of science in a content course that was specifically designed for prospective elementary teachers (Abd-El-Khalick, 2001; Bianchini & Colburn, 2000; Murcia & Schibeci, 1999). As discussed in Section 3.6, Abd-El-Khalick used the VNOS with 30 female prospective elementary teachers in his physics course, while Bianchini and Colburn used videotape analysis of nature of science instruction in the same course that I investigated in my study (*A Process Approach to Science—SCED 401*). Both of these studies used only qualitative approaches. Murcia and Schibeci's (1999) study, however, involved 73 preservice primary teachers enrolled in an introductory physical

Table 3.3

Summary of Studies on Elementary Teachers' Understandings of Nature of Science Between 1991 and the Present

Year	Author(s)	Title of Study	Journal or Conference	Method and Major Findings
1993	Pomeroy, D.	Implications of Teachers' Beliefs about the Nature of Science: Comparison of the Beliefs of Scientists, Secondary Science Teachers, and Elementary Teachers	*Science Education*	Investigated differences between 71 scientists' & 109 teachers' attitudes & beliefs about the nature of science. Pomeroy developed her own 50-item questionnaire with a five-point Likert scale. Discovered that scientists & secondary science teachers hold mainly traditional beliefs about the nature of science, while elementary teachers held more modern, constructivist views.
1994	Abell, S., & Smith, D.	What Is Science?: Preservice Elementary Teachers' Conceptions of the Nature of Science	*International Journal of Science Education*	Analyzed written responses from 140 preservice elementary teachers taking a science methods course using analytic induction to find patterns/themes (based on the one question). Found students had realist & positivist views of the scientific enterprise; they place little emphasis on social or cultural implications of science.
1996	Shapiro, B.	A Case Study of Change in Elementary Student Teacher Thinking during an Independent Investigation in Science: Learning about the "Face of Science That Does Not Yet Know"	*Science Education*	Studied one preservice student teacher during an elementary methods course assignment in which they design an independent investigation. Used survey, interviews, & repertory grid technique to investigate the teacher's ideas about nature of knowledge acquisition in science prior, during & after assignment.
1997	Mellado, V.	Preservice Teachers' Classroom Practice and Their Conceptions of the Nature of Science	*Science and Education*	Participants were four student teachers of primary & secondary science in Spain. Analyzed nature of science conceptions & compared these to their classroom practice. Researcher found no correspondence between conceptions of the nature of science & their teaching practice.
1998	Hammrich, P.	Cooperative Controversy Challenges Elementary Teacher Candidates' Conceptions of the "Nature of Science"	*Journal of Elementary Science Education*	Described strategy of having students engage in a debate of a nature of science issue in a science methods course (*N*=37). Before lesson, 73% felt nature of science was fact based but, after the lesson, 60% felt nature of science was a combination of factual information & belief.
1999	Meichtry, Y.	The Nature of Science & Scientific Knowledge: Implications for a Preservice Elementary Methods Course	*Science and Education*	Used modified *NSKS* with 67 students in an elementary science methods course. Investigated the effectiveness of nature of science teaching strategies on improving students' understandings of the nature of science. Results indicated statistically significant improvements for all four scales of the *NSKS* (Creative, Developmental, Testable, Unified).
1999	Murcia, K., & Schibeci, R.	Primary Student Teachers' Conceptions of the Nature of Science	*International Journal of Science Education*	Studied 73 preservice primary teachers in a physical science unit in Western Australia. Wanted to see if there were any differences between mature-age & school-leaver students, & to evaluate the effectiveness of newspaper science reports in assessing nature of science conceptions. Method included

				questionnaire given in week one which had three sections; seven open-ended questions on newspaper article, T/F/Don't Know items from *Test of Basic Scientific Literacy* (Laugksch & Spargo, 1996), & background information on students. Found no difference between mature-age & school-leavers, & newspaper science reports were effective for probing nature of science.
2000	Akerson, V., Abd-El-Khalick, F., & Lederman, N.	Influence of a Reflective Explicit Activity-Based Approach on Elementary Teachers' Conceptions of Nature of Science	*Journal of Research in Science Teaching*	Studied 50 preservice teachers in an elementary methods course. Method included use of *VNOS*, student interviews, 10 activities, explicit nature of science instruction, & reflective discussions. Results indicated most students held 'naïve' views of the nature of science, but during the course they made gains on their understanding of three aspects of the nature of science (empirical, tentative, & creative). No gains were made on subjectivity or social & cultural aspects.
2000	Bianchini, J., & Colburn, A.	Teaching the Nature of Science Through Inquiry to Prospective Elementary Teachers: A Tale of Two Researchers	*Journal of Research in Science Teaching*	Used 20 hours of video analysis in SCED 401 at California State University, Long Beach, & investigated use of both implicit & explicit approaches to teach nature of science to prospective elementary teachers. Found role of teacher is critical for initiating discussions at the appropriate time (i.e., creating reflective situations during classroom discussions).
2001	Abell, S., Martini, M., & George, M.	'That's What Scientists Have To Do': Preservice Elementary Teachers' Conceptions of the Nature of Science During a Moon Investigation	*International Journal of Science Education*	Study involved a science methods course & a six-week unit on the moon. Self-study/action research with field notes. Involved 11 students who kept a journal and were interviewed. Authors agree that the nature of science must be explicitly taught.
2001	Abd-El-Khalick, F.	Embedding Nature of Science Instruction in Preservice Elementary Science Courses: Abandoning Scientism, But…	*Journal of Science Teacher Education*	Study involved 30 female students in a Physics course. Intervention consisted of five nature of science activities. Used *VNOS* followed by interviews. Found students began with naïve, scientistic worldviews & moved to naïve, relativistic worldviews, & that students could not apply their nature of science understandings to a new context. Suggested investigating the link between formal operational stage & understanding nature of science. Stressed that an explicit reflective activity-based approach to teach nature of science is better than an implicit approach that uses hands-on inquiry activities alone.
2002	Gess-Newsome, J.	The Use and Impact of Explicit Instruction about the Nature of Science and Science Inquiry in an Elementary Science Methods Course	*Science and Education*	Described & evaluated an elementary science methods course in which nature of science & scientific inquiry were embedded & explicitly taught. Used *NSKS*. Results indicate students acquired a more appropriate, 'blended' view of science.
2002	Bright, P., & Yore, L.	Elementary Preservice Teachers Beliefs about the Nature of Science & Their Influence on Classroom Practice	Annual meeting of NARST, New Orleans, LA	Documented changes in beliefs over a year-long science methods + practicum course. Pretest/posttest design using *NSKS* with 50 elementary teachers. Significant gains in three out of six *NSKS* scales were found: Creative, Developmental, & Unified. But teachers could not transfer to classroom practice.
2002	Matkins, J., Bell, R.,	Impacts of Contextual and Explicit Instruction on Preservice Elementary	Paper presented at the annual meeting	Used *VNOS* with 75 preservice elementary teachers in a science methods course. Study assessed the effectiveness of introducing a controversial science &

	Irving, K., & McNall, R.	Teachers' Understandings of the Nature of Science	of the Association for the Education of Teachers of Science (AETS)	technology-based issue (global climate change) on teachers' understandings of nature of science, & effectiveness of an explicit versus an implicit instructional approach. Findings showed that *VNOS* posttest responses better reflected current understandings of the nature of science with the explicit approach.
2002	Cobern, W.C., & Loving, C.C.	Investigation of Preservice Elementary Teachers' Thinking about Science	*Journal of Research in Science Teaching*	Preservice elementary teachers completed *Thinking About Science* survey addressing broad relationships of science to nine areas of society and culture. Views were compared to commonly-held worldviews of science portrayed in the media and popular science. Results indicated that elementary teachers discriminate with respect to different aspects of culture, but are not antiscience.
2003	Akerson, V. & Abd-El-Khalick, F.	Teaching Elements of Nature of Science: A Yearlong Case Study of a Fourth-Grade Teacher	*Journal of Research in Science Teaching*	In-depth case study of one 4th grade teacher involving *VNOS.* Understandings focused on three of the eight 'aspects' of nature of science. Purpose was to see what supports were needed for teacher to explicitly teach nature of science. Teacher needed researcher to model explicit nature of science instruction.
2004	Akerson, V. & Abd-El-Khalick, F.	The Influence of Instruction in Metacognitive Strategies on Preservice Early Childhood Teachers' Conceptions of Nature of Science	Paper presented at the annual meeting of the National Association for Research in Science Teaching	Used *VNOS* and *Metacognitive Awareness Inventory* (MAI) with 48 female preservice early childhood teachers in a science methods course. Purpose was to assess relationship between training in, & use of, metacognitive strategies (concept mapping, case studies) and 'informed' views of nature of science. Preservice teachers who received the metacognitive strategies instruction had more 'informed' views of three nature of science aspects.
2004	Lederman, J. & Lederman, N.	Early Elementary Students' and Teachers' Understandings of Nature of Science and Scientific Inquiry: Lessons Learned From Project ICAN	Paper presented at the annual meeting of the National Association for Research in Science Teaching	Involved 58 inservice primary teachers & a new *VNOS* designed for very young children. Purpose was to evaluate an NSF-funded teacher enhancement project (Inquiry, Context, & Nature of Science-ICAN), & to compare teachers' understandings of nature of science with their students' understandings. Mainly focused on a case study of one Grade 1—2 teacher.
2004	Abd-El-Khalick, F. & Akerson, V.	Learning as Conceptual Change: Factors Mediating the Development of Preservice Elementary Teachers' Views of Nature of Science	*Science Education*	Used *VNOS* with 28 preservice elementary teachers enrolled in a science methods course. Study identified factors in participants' learning ecologies that mediated the effectiveness of explicit reflective approach to nature of science instruction. A subsample of six participants served as a focus group. Focus group indicated intervention was effective in developing nature of science views that were mediated by motivational, cognitive, and worldview factors.
2004	Bartholomew, J. & Ratcliffe, M.	Teaching Students "Ideas-About-Science": Five Dimensions of Effective Practice	*Science Education*	Qualitative study with 11 UK elementary & secondary teachers asked to teach a set of 'ideas-about-science'. Investigated factors that afforded or inhibited teachers' pedagogic performance for teaching nature of science. Factors included teachers' knowledge & understanding of nature of science, conceptions of their own role, use of discourse, learning goals, & nature of classroom activities. Researchers found that establishing a context in which it is possible for students to engage in reflexive epistemic dialogue is crucial for improving understandings of the nature of science.

science unit in Western Australia. The researchers evaluated the effectiveness of using current events in terms of nature of science topics in the newspaper for improving teachers' conceptions of the nature of science. Their questionnaire included seven open-ended questions on the newspaper article, True/False/Don't Know items from the *Test of Basic Scientific Literacy* (Laugksch & Spargo, 1996), and questions about the teachers' background.

Considering the many advantages in having several *grain sizes* (the use of different-sized samples for different research questions varying in extensiveness and intensiveness) (Fraser, 1999), a gap appears to exist in the nature of science field because so few studies use a mixed-methods approach in the context of a science content course.

3.7 Summary of Chapter

All five of my research questions outlined in Chapter 1 mention 'understandings of the nature of science'. Therefore, it was necessary to include a review of literature related to the nature of science. Like the field of classroom learning environments discussed in Chapter 2, nature of science research has spanned several decades and includes several types or approaches that can be taken during a study. This chapter focused mainly on prospective, preservice and inservice teachers' conceptions of the nature of science because my study's sample consisted of 525 female prospective elementary teachers. Issues and trends in nature of science research that were relevant to my study (e.g., instructional approaches, authentic scientific inquiry) were discussed (Section 3.5) in anticipation that the information would guide the analyses of qualitative data generated by the VNOS, the interviews with students in the intervention classes, and the concept maps (details of the qualitative methods of data analysis are provided in Chapter 4).

Although students and the majority of teachers have never heard of the term 'nature of science', it has been a persistent goal of science education for close to 100 years. Even for scholars outside the nature of science field, the term conjures up various interpretations. Section 3.2 provided a detailed definition and explanation for the nature of science from a variety of sources. Nevertheless, one strict definition has not been agreed upon by historians, sociologists, philosophers of science, or science teacher educators. This is why the nature of science literature often does not include ‘the’ in front of ‘nature of science’. Section 3.2 also included a consensus list of nature of science objectives gathered from 11 international science standards documents. Instruments that assess understandings of nature of science are based on several of these objectives. Section 3.3 provided an overview of nature of science as an educational objective going back to the early 1900s.

Section 3.4 reviewed the questionnaires that I used in my study. Section 3.4.1 provided details about the development and validation of the *Nature of Scientific Knowledge Survey—NSKS*. Section 3.4.2 described the *Views of Nature Of Science–Form C* (VNOS–C), an open-ended questionnaire that includes 10 items, although I only used four items in my study. Section 3.4 also provided a table that summarized additional standardized convergent instruments. Throughout these sections, relevant and noteworthy studies were summarized.

The last major section in the chapter, Section 3.6, provided an overview of nature of science research related specifically to elementary teachers. Because my study involved prospective elementary teachers, it was appropriate to pay particular attention to other studies that used a similar population. Section 3.6.1 looked at studies between 1950 and 1990, of which only two out of 19 studies involved prospective, preservice or inservice elementary teachers. Section 3.6.2, in contrast, provided an overview of the 20 out of 55 studies on the nature of science that were conducted after 1990 and involved elementary teachers. Most of the details of these studies were summarized in a comprehensive table. From reviewing this table, one can see that my study is timely because it combined quantitative and qualitative approaches to investigate prospective elementary teachers’ understandings of the nature of science in an innovative course specifically designed for future teachers. Only three studies used a mixed-methods approach, and only three studies investigated understandings of the nature of science in the context of a science content course for elementary teachers.

Chapter 4—Research Methods describes the details of the methodology employed in my study.

Chapter 4

RESEARCH METHODS

4.1 Introduction and Overview

This chapter describes the quantitative and qualitative methods that I used to assess perceptions of the learning environment, attitudes towards science, and understandings of the nature of science among a sample of female prospective elementary teachers. The prospective elementary teachers were enrolled in an innovative science course, called *A Process Approach to Science, SCED 401*, during 2002 and 2003 at California State University, Long Beach. Blending both quantitative and qualitative methodologies into a single study has been recommended by many educational researchers, particularly in the field of learning environments research (Fraser & Tobin, 1991; Tobin & Fraser, 1998). This chapter contains eight main sections, with numerous sections divided into smaller subsections for ease of reading. The following list of sections provide an overview of the chapter.

- Section 4.2–Participants in the Study
- Section 4.3–Role of the Researcher
- Section 4.4–Nature of the Study–Combining Quantitative and Qualitative Methods
- Section 4.5–Questionnaires
- Section 4.6–Interviews With Students in the Intervention Classes
- Section 4.7–Concept Maps From the Intervention Classes–Nature of Science and the Seabird Project
- Section 4.8–Methods of Data Analysis
- Section 4.9–Limitations of Method

A large section entitled, Questionnaires, is divided into four subsections. Section 4.5.1 describes the two learning environment instruments that I used to produce the survey for my study. Scales were drawn from the *Science Laboratory Environment Inventory, SLEI* (Fraser et al., 1992a) and *What Is Happening In this Class?* (Fraser et al., 1996). This resulted in 46 items in six scales (Student Cohesiveness, Instructor Support, Investigation, Cooperation, Open-Endedness, and Material Environment). After the learning environment scales, the Enjoyment of Science Lessons scale from the *Test of Science-Related Attitudes, TOSRA* (Fraser, 1981) was added. The TOSRA is described in Section 4.5.2. Students' understandings of the nature of science were assessed by the *Nature of Scientific Knowledge Survey, NSKS* (Rubba & Anderson, 1978) and this instrument is described in Section 4.5.3. The NSKS consists of 48 items and six scales, although not all six scales were used in my analyses. To triangulate, complement, and expand data from the NSKS, qualitative data were collected with *Views of Nature Of Science–Form C, VNOS–C* (Lederman et al., 2002). This instrument and the items that I selected are discussed in Section 4.5.4.

Section 4.8 is another large section that is divided into six subsections. Section 4.8.1 describes how I validated the science learning environment and attitude scales, and the *Nature of Scientific Knowledge Survey*. Section 4.8.2 explains how I analyzed differences between previous laboratory courses and SCED 401 with regard to learning environment and attitudes towards science. I also analyzed students' understandings of the nature of science in a pretest-posttest design. In Section 4.8.3, I describe how I analyzed differences between classes of SCED 401 that experienced an intervention with classes that did not. The intervention involved adding real scientific research data on Antarctic seabirds for the students to use during their experimental design project. The project was both a guided inquiry (Colburn, 2000) and an authentic scientific inquiry investigation (Roth, 1995; Schwartz et al., 2004). Section 4.8.4 describes how I analyzed associations between the science learning environment and the two student outcomes of attitude and understandings of the nature of science. Section 4.8.5 describes how I analyzed the data from *Views of Nature Of Science, VNOS*, while Section 4.8.6 discusses how I analyzed information from interviews and concept maps of students in the intervention classes.

The last two sections of the chapter discuss limitations of the various methods, and then I provide a summary of the chapter.

4.2 Participants in the Study

Participants in the study were 525 female prospective elementary teachers from 27 classes enrolled in the course, *A Process Approach to Science*–SCED 401, during 2002 and 2003 at California State University, Long Beach. Most classes were offered during the day, two sessions per week for a total of four hours, with one class usually offered in the evenings (excluding the summer of 2003). Therefore, the majority of students (prospective elementary teachers) were full-time students who were pursuing a Bachelor of Arts degree with a major in Liberal Studies. Liberal Studies is the most popular major at the university, with over 2,500 students declaring it as their major. Students usually take SCED 401 during their senior or fourth year, before applying to a teacher preparation program in which they earn their elementary school teaching credential. About 50% of graduating California State University, Long Beach, students apply to and are accepted into our elementary teacher preparation program every fall and spring semester.

Class sizes for SCED 401 were small and ranged from 14–32, with an average of 24.5 students during the four semesters when data were collected. In a typical class, the majority of students are female with only one or two males. Historically, in many countries of the world, elementary school teaching tends to attract mainly females due partly to a prevalent stereotypical view that it is a low-status and low-paying profession. To control for the variable of gender in my study, male students were eliminated from the sample, although they did not realize this and were also asked to complete the surveys. The female students' average age was approximately 24 years, with a median age of 23 years, and a range from 20 to 52 years of age. Although many learning environment studies do investigate differences in perceptions between male and female students, none of my research questions focused on this aspect. Because only 5% of the prospective elementary teachers in the SCED 401 classes were male, it was not feasible to sample a comparable number of male and female students.

A combination of seven part-time and full-time instructors taught SCED 401 during the four semesters in 2002 and 2003 (maximum of six instructors during any one semester). All instructors followed a similar syllabus. On average, the instructors have taught the course 8.7 times or semesters (range of 1–17). All instructors have considerable K–12 science teaching experience, with an average of 10.3 years of experience and a range of three to 23 years of teaching experience. The instructors' college/university teaching experience was not as extensive as their K–12 experience. The seven instructors have taught part-time for an average of 2.8 years, and five instructors have taught full-time for an average of 4.9 years (four of the five in tenure-track positions).

4.3 Role of the Researcher

During the study, I was a participant-observer (Arsenault & Anderson, 1998; Atkinson & Hammersley, 1994). I taught six of the 27 (22%) classes of SCED 401 (two classes in each of three semesters), but also I collected and analyzed the data from questionnaires, interviews and concept maps. On the first day of the course, I visited all 27 classes and explained the purpose, confidentiality, and anonymity of the study, and how to complete the surveys. This procedure was repeated again during the last week of classes. I distributed and collected all questionnaires and informed consent forms. During the summer semester of 2003, I withdrew from the university teaching setting, and checked and reflected upon preliminary data analysis results. During the last semester of data collection (fall of 2003), I gathered additional questionnaire data and new qualitative data from interviews with students in my two classes.

During the study, I was a full-time lecturer with five years of university teaching experience, and eight years of elementary and secondary school science teaching experience obtained in Canada, Hong Kong, and the United States. By the end of the data collection period, I had taught SCED 401 for a total of 17 times.

4.4 Nature of the Study–Combining Qualitative and Quantitative Methods

My study combined quantitative and qualitative data-gathering methodologies, an approach strongly encouraged by learning environment researchers throughout the 1990s and into the 21st Century (Aldridge et al., 1999; Fraser & Tobin, 1991; Tobin & Fraser, 1998). The study's main purpose was to evaluate and describe the impact of an innovative science course called *A Process Approach to Science*, SCED 401, on prospective elementary teachers' perceptions of the learning environment, attitudes towards science, and understandings of the nature of science. In particular, my evaluation identified differences between students' (prospective elementary teachers) *previous* science laboratory courses and SCED 401 in relation to six learning environment scales and one attitude scale. Understandings of the nature of science were assessed using a pretest-posttest design. Students completed a Likert-style questionnaire and two open-ended response items based on their prior *overall* science education experience (not focusing on just one course), and then completed the same questionnaire and open-ended items again during the last week of classes, after they had completed SCED 401. In addition, I examined the validity and reliability of all instruments used with this population of university students.

In discussing mixed-methods studies, the term *triangulation* often surfaces. Denzin (1978) is given credit for coining the term triangulation, a term borrowed from navigation and military strategy, to argue for a combination of methodologies in one study (Creswell, 1994). Triangulation is based on the assumption that biased judgments are reduced when more than one data source, investigator, or method is used (Anderson, 1998; Creswell, 1994; Denzin & Lincoln, 1994, 1998; Fraser & Tobin, 1991; Grundy, 1995; Lincoln & Guba, 1985; Mathison, 1988), thus enhancing validity and credibility (Fraser & Tobin, 1991; Miles & Huberman, 1994). I did make use of triangulation in my study. My data sources included using questionnaires (both convergent, paper- and-pencil format, and open-ended response items), interviews with a subsample of students who completed the questionnaires, and concept maps that a second subsample produced on a final examination paper. Triangulation in my study, therefore, involved both a *within-methods* and a *between-methods* approach (Creswell, 1994).

In addition to improving validity and credibility, Greene, Caracelli, and Graham (1989) state five additional purposes for combining methods in a single study, and these purposes were relevant to my study:

> 1. Triangulation in the classic sense of seeking convergence of results.
> 2. Complimentary, in that overlapping and different facets of a phenomena may emerge (e.g., peeling the layers of an onion).
> 3. Developmentally, wherein the first method is used sequentially to help inform the second method.
> 4. Initiation, wherein contradictions and fresh perspectives emerge.
> 5. Expansion, wherein the mixed methods add scope and breadth to a study.
>
> (Creswell, 1994, p. 175)

Several metaphors and aphorisms are used to support the use of multiple theoretical perspectives and multilevel designs. Greene et al. (1989) used the example of peeling the layers of an onion to describe complementarity. Another example is ‘bricoleurs’ who “select from the available materials those that are satisfactory for completing a task or producing a particular product” such as “a quilt comprised of numerous patches, some overlapping and others separate” (Tobin & Fraser, 1998, p. 623). The idea of *grain sizes* (the use of different-sized samples for different research questions varying in extensiveness and intensiveness) is also effective in describing studies that combine different research methods (Fraser, 1999). My grain sizes or samples ranged from five to 525.

Although the merits of combining both quantitative and qualitative methods are clear, each methodology has its strengths as well. Learning environment questionnaires are easy to use and economical, and appropriate for district, school, program or course evaluations involving a coarse grain size (Tobin & Fraser, 1998). They were developed using Lewin (1936) and Murray’s (1938) idea of ‘beta press’–a description of the environment as perceived by the people themselves in the environment (e.g., prospective elementary teachers taking SCED 401). This is in contrast to ‘alpha press’–a description of the environment as observed by a detached observer, which is a common approach used in psychology and general educational research. Lewin and Murray pointed out that there are many advantages in considering beta press, particularly in schools and classrooms, because an outside observer can miss important and relevant events and interactions. Analysis of surveys involves a deductive process and rigorous statistical procedures (which are discussed in Section 4.8). Many learning environment surveys, such as the *My Class Inventory, Questionnaire on Teacher Interaction, Science Laboratory Environment Inventory, Constructivist Learning Environment Survey,* and *What Is Happening In this Class?*, have been used with thousands of elementary, secondary, and university students in several countries throughout the world, and have strong validity and reliability. There is no need to ‘reinvent the wheel’ with so many instruments available (Fraser, 1986). Recombining scales and omitting others (as I did in my study, and discuss in Section 4.5) to suit particular contexts and research questions is also acceptable.

Qualitative data-gathering methods use an analytic inductive (Bogdan & Biklen, 1992; Goetz & LeCompte, 1984; Lindesmith, 1947; Merriam, 1998) or recursive process in which information is reviewed with an assertion/question or theme (Erickson, 1998; Seidman, 1991) in mind, and then revised and reviewed again, until fresh new insights and patterns emerge.

Glaser and Strauss (1967) call this process the *constant comparative method*, and it is described further in Section 4.5.4 and Section 4.6. Erickson (1998) uses the aphorism “to draw is to leave things out” (p. 1162) to describe qualitative research because the researcher must constantly decide what information to attend to and what information not to attend to. He further explains that the qualitative researcher must provide both *general* descriptions of data and *particular* descriptions (quotes as evidence) so that the reader can see patterns in the forest but also become familiar with some of the trees (Erickson, 1998, p. 1169). Effective qualitative data analysis results in rich, contextual narratives that complement and expand the quantitative data (Fraser & Tobin, 1991; Tobin & Fraser, 1998). Combining quantitative and qualitative methods created both depth and breadth in my study.

4.5 Questionnaires

The following sections describe the instruments that I used in my study. For the laboratory learning environment survey, I extracted scales from the *Science Laboratory Environment Inventory*–SLEI (Fraser et al., 1992a, 1992b) and *What Is Happening In this Class?*–WIHIC (Fraser et al., 1996). To assess attitudes towards science, I used the Enjoyment of Science Lessons scale from the *Test of Science-Related Attitudes*–TOSRA (Fraser, 1981). To assess understandings of the nature of science, I used the *Nature of Scientific Knowledge Survey*–NSKS (Rubba & Anderson, 1978), as well as several open-ended response items from *Views on Nature Of Science, Form C*–VNOS–C (Lederman et al., 2002).

The scales from the SLEI, WIHIC, TOSRA, and NSKS resulted in a six-page form. On the first page, students were asked to indicate their instructor’s last name and their student identification number, age, and gender, and then to name their previous science laboratory course. If a student happened to take two laboratory courses previously, they were advised to select one of them. If a student informed me that their previous science course was taken entirely on the Internet, I advised them to think about the course previous to their Internet course (this only occurred about three or four times). A handful of students complained that their previous laboratory course was ‘so long ago’ and that they could not remember the course very well. The vast majority of students, however, seemed to have no trouble remembering their previous laboratory class which, in most cases, was one of the prerequisite courses needed for SCED 401. The prerequisite courses at our university include Physical Science 112, Biology 200, and Geology 106 or Geology 102 with 104. Some of the students took their first one or two years towards their degree at a community college and then transferred to California State University, Long Beach. The local community colleges have a list of science courses that are equivalent to the ones listed above.

All students completed the learning environment/attitude questionnaire and the NSKS on the first day of the course, but a research assistant entered only the females' scores into a database (Excel spreadsheet). Other information recorded in the database included the last four digits of each female student's identification number, the instructor's last name, the semester, and the name of the previous science laboratory course. Later, I exported all the information into the SPSS, Version 11.01, data analysis software application.

4.5.1 Modified Science Learning Environment Questionnaire

The course, *A Process Approach to Science*–SCED 401, is a hybrid-style course in which the lecture and laboratory components take place in the same classroom with the same instructor. The room is fully equipped with the usual laboratory equipment and supplies, although only one small sink with cold running water is available and the room has neither air-conditioning nor a fume hood for dissipating harmful chemical vapors. Rather than the traditional bench-style laboratory tables, the room has six tables measuring approximately one meter by one meter. Four to five students sit around each table in comfortable, padded chairs.

Due to the nature of the course and its setting, I chose two scales (Material Environment and Open-Endedness) from the *Science Laboratory Environment Inventory*, SLEI. The SLEI was developed with the unique instructional setting of the laboratory in mind, has strong validity and reliability, and has been extremely valuable in assessing and describing laboratory teaching and learning in many countries of the world (Fraser et al., 1992a). For both SLEI scales, the tense used for the item wording was changed from the original SLEI (i.e., from the present tense to the past tense). In addition, one item from Material Environment was reworded slightly to reflect the variable climate in Southern California. The tense change and rewording of the item are shown below.

Original SLEI—*I find that the laboratory is hot and stuffy.*

Reworded item in my study—*I found that the laboratory was just the right temperature to work in.*

Aside from the tense change, no rewording of items was made for Open-Endedness. This scale was extremely relevant to my study because SCED 401 is taught by science educators (rather than scientists) who use nontraditional science teaching methods. They use a combination of 'guided inquiry and open inquiry' (Colburn, 2000) laboratory activities that encourage divergent thinking and cooperative learning. Colburn defines 'guided inquiry' as: "The teacher provides only the materials and problem to investigate. Students devise their own procedure to solve the problem" (p. 42). 'Open inquiry' is "similar to guided inquiry, with the addition that students also formulate their own problem to investigate. Open inquiry, in many ways, is analogous to doing science" (p. 42).

Three of the SLEI scales were not used for my study. Integration and Rule Clarity were not relevant to the course. In SCED 401, students do not spend time in a lecture hall or auditorium for the theory component of the course, and then proceed to a laboratory class for experiments and investigations. As described earlier, both components (theory and practical work) are integrated in the one classroom setting. Rule Clarity, in which behavior in the laboratory is guided by formal rules, was not a concern for these university-level students.

The original SLEI did not identify scale names, and had items arranged in a cyclic order in blocks of five (e.g., the first item assessed Student Cohesiveness, the second item assessed Open-Endedness, and so on). This arrangement was thought to reduce bias (favorably or unfavorably) because participants could not determine the researcher's goal or purpose in using the questionnaire. Studies with the *Constructivist Learning Environment Survey*, however, found that presenting items in context with scale names identified, did not adversely affect the quality of responses (Taylor et al., 1997). In my study, I also arranged all items in a scale in a single block along with the scale's name.

I also used four out of a possible seven scales from *What Is Happening In this Class?*–WIHIC (Instructor Support, Student Cohesiveness, Investigation, and Cooperation). The WIHIC was chosen for three reasons. First, it is the most recent and widely-used instrument, second, it does not contain any reverse-scored items and, third, it "combines scales from several past questionnaires to bring parsimony to the field of learning environments" (Aldridge et al., 1999, p. 49). Task Orientation and Involvement were not chosen because I felt that they were not relevant to senior-level university students, while Equity might have provided some interesting data but its inclusion would have made the questionnaire too long, and males were present in only small numbers in the classes in my sample.

The number of items in each of the six scales extracted from *What Is Happening In this Class?* (WIHIC) and the *Science Laboratory Environment Inventory* (SLEI) are provided in Table 4.1. A total of 46 items comprised the science learning environment questionnaire. All three of Moos' dimensions are represented in the questionnaire. Rudolf Moos was a professor of psychiatry and behavioral sciences at Stanford University who spearheaded learning environment research in schools and classrooms throughout the 1970s. Moos' dimensions were developed from a 'social ecological' perspective in which one investigates how people grow and adapt to various environments. *Relationship* dimensions identify the nature and intensity of personal relationships within the environment and assess the extent to which people are involved in the environment and support and help each other. *Personal Development* dimensions assess basic directions along which personal growth and self-enhancement tend to occur. *System Maintenance and Change* dimensions involve the extent to which the environment is orderly, clear in expectations, maintains control and is responsive to change (Fraser, 1998a). A description of each scale and a sample item are provided in Table 4.2.

Table 4.1
Overview of Scales Used to Assess Science Learning Environment

	Scales Classified According to Moos' Scheme		
Instrument	Personal Development	Relationship	System Maintenance and Change
WIHIC	Investigation (8)* Cooperation (8)	Student Cohesiveness (8) Instructor Support (8)	
SLEI	Open-Endedness (7)		Material Environment (7)

*Numbers in parentheses indicate number of items in that scale.

4.5.1.1 Scoring

Scores of 1, 2, 3, 4, and 5 were allocated to the frequency responses of *Almost Never, Seldom, Sometimes, Often,* and *Almost Always,* respectively. Students simply circled the appropriate number directly on the form. A '3' was given for the occasional omitted item. However, a few students missed entire scales and even entire pages. In these cases, the student's questionnaire was not used in the study. Three of the items for Material Environment and one for Open-Endedness were reverse-scored, meaning that 5 was given for *Almost Never* and 1 for *Almost Always*, and so on. No items on WIHIC were reverse-scored.

Table 4.2
Descriptive Information for each Science Learning Environment Scale

Scale Name	Description	Sample Item
Student Cohesiveness	Extent to which students know, help and are supportive of one another.	I worked well with other students. (+)
Instructor Support	Extent to which the instructor helps, befriends, trusts, and shows interest in students.	The instructor's questions helped me to understand. (+)
Investigation	Emphasis on the skills and processes of inquiry and their use in problem solving and investigation.	I found out answers to questions by doing investigations. (+)
Cooperation	Extent to which students cooperate rather than compete with one another on learning tasks.	When I worked in groups, there was teamwork. (+)
Open-Endedness	Extent to which the laboratory activities emphasize an open-ended divergent approach to experimentation.	The instructor decided the best way for me to carry out the laboratory experiments. (-)
Material Environment	Extent to which the laboratory equipment and materials are adequate.	The laboratory equipment that I used was in poor working order. (-)

\+ Items designated (+) are scored 1, 2, 3, 4 and 5, respectively, for the responses Almost Never, Seldom, Sometimes, Often and Almost Always.
\- Items designated (-) are scored 5, 4, 3, 2 and 1, respectively, for the responses Almost Never, Seldom, Sometimes, Often and Almost Always.

Reverse-scoring was originally a psychometric strategy to reduce the likelihood of students biasing their responses to either end of the response scale (e.g., Almost Always, Almost

Never), and to guard against passive responses where the respondent does not make a conscious choice or effort. Taylor et al. (1997), however, found that negatively-worded items in an early version of the *Constructivist Learning Environment Survey* confused students. In addition, other studies found higher reliability when all of the items were worded positively (Chamberlain & Cummings, 1984; Schreisheim, Eisenbach, & Hill, 1991). A recent study led to a recommendation not to mix positively-worded and negatively-worded items in the same questionnaire (Barnette, 2000). Barnette recommended using directly-worded stems (i.e., statements do not contain the word 'not') with bi-directional response options (i.e., half of the items have options going from *Almost Never* to *Almost Always*, and the other half have options going from *Almost Always* to *Almost Never*) to guard against acquiescence and response set behavior. In the present study, all items are positively-worded although response options are not bi-directional.

4.5.1.2 Actual and Preferred Forms of the SLEI and WIHIC

Both the SLEI and the WIHIC are available in an *actual* and a *preferred* form. The actual form assesses students' perceptions of how they actually perceive the science classroom or laboratory environment. The preferred form measures perceptions of the environment ideally liked or preferred. Wording is slightly changed in the preferred form. In many studies, the actual and preferred forms are combined into one questionnaire, and are appropriate for person-environment fit studies of whether students achieve better in their preferred environment. In my study, assessing the preferred science laboratory environment was not necessary because my main purpose was to measure differences between students' *previous* laboratory class and SCED 401. Consequently, I created an *actual* form from the SLEI and the WIHIC for my study.

4.5.1.3 Personal and Class Versions

As mentioned in Section 4.4–Nature of the Study, Lewin (1936) and Murray (1938) described the distinction between *alpha press* (the environment as observed by an external observer) and *beta press* (the environment as perceived by milieu inhabitants). Stern et al. (1956) extended beta press further to distinguish between *private* beta press (an individual's personal view of the environment) and *consensual* beta press (the shared view that the members of a group hold about the environment). In schools and classrooms, we often want to differentiate between subgroups (e.g., Asian versus African American ethnicities, or males versus females). Consequently, based on the early work by Stern et al. (1956), another version of the SLEI was developed. The need for a *personal* version arose because it was recognized that item wording on the *class* version forced students to respond based on their perceptions of the class as a single entity (Taylor et al., 1997). However, a student's perceptions of his or her role within the classroom provides valuable information as well. Fraser and Tobin (1991) advocated that a *personal* version was more valid, especially in research that involved case studies of individual students or subgroups within classes. Thus, a *personal* version of the SLEI was developed alongside the usual *class* version. The SLEI, in fact, was the first instrument to introduce this distinction between *class* and *personal* versions. In my study, I used a *personal* version.

4.5.2 Test of Science-Related Attitudes (TOSRA)

Eight items from the Enjoyment of Science Lessons scale from the *Test of Science-Related Attitudes* were also employed in my study (and included at the end of the science learning environment questionnaire). The Enjoyment of Science Lessons scale is one of seven scales in the original TOSRA, and corresponds directly with one of Klopfer's (1971) categories in his classification scheme (i.e., enjoyment of science learning experiences). The TOSRA was validated with three separate samples involving 2,595 junior and senior secondary science students in Australia and the United States (Fraser, 1981; Fraser & Butts, 1982). Although the alpha reliability was high for all seven scales of the TOSRA, it was highest for the Enjoyment of Science Lessons scale for the three samples (α=0.92) (Fraser & Butts, 1982, p. 148).

The Enjoyment of Science Lessons scale uses the same five-point frequency response options as the learning environment scales. Three of the eight items were reverse-scored. The eight items were slightly reworded from the original TOSRA and, again, past tense was used. Sample items are provided below.

> *I looked forward to lessons.*
> *The class was one of the most interesting college classes.*

4.5.3 Nature of Scientific Knowledge Survey (NSKS)

During the past 40 years, more than 20 standardized and convergent paper-and-pencil instruments have been developed to assess understandings of the nature of science (Lederman et al., 2002). When Lederman et al. (1998) provided a comprehensive review of many of these instruments, the *Views on Science-Technology-Society (VOSTS)* (Aikenhead et al., 1989) and *Nature of Scientific Knowledge Survey (NSKS)* (Rubba & Anderson, 1978) received favorable comments. Although VOSTS was considered the superior instrument by Lederman et al. (1998), I decided not to use it in my study because of its length and complexity, and because it did not produce numerical scores.

I decided to use the simpler *Nature of Scientific Knowledge Survey,* NSKS, to assess students' understandings of the nature of science in a pretest-posttest design. The NSKS has 48 items in six scales, namely, Amoral, Creative, Development, Parsimonious, Testable, and Unified, based upon Showalter's (1974) factors of the nature of science. Table 4.3 provides a description of each scale and a sample item. Items were arranged in cyclic fashion throughout eight sections or blocks, in a style similar to the SLEI and other early learning environment instruments. Scale names were not identified on the questionnaire.

The NSKS was developed, validated and found to be reliable for high school level students (Rubba & Anderson, 1978), but validity and reliability needed to be reassessed with my population of prospective elementary teachers. Like the learning environment and attitude scales, the NSKS scales were individually scored with their validity and reliability established for each scale (discussed in more detail in Section 4.8–Methods of Data Analysis).

The NSKS' response options are based on a Likert response scale consisting of *Strongly Disagree, Disagree, Not Sure, Agree,* and *Strongly Agree.* Half of the items are reverse-scored, and many of the statements use the word *not*. Many of the prospective elementary teachers in my study were from various ethnic and cultural backgrounds, and a certain percentage learned English as a second language. Consequently, to draw students' attention to the wording and meaning of these statements, I underlined the word 'not' and used bold face font. Lederman et al. (1998) criticized the NSKS on this issue of the use of the word *not.* They pointed out that many pairs of items from the same scale are worded identically, except that one word is worded negatively or *not* is used. Such redundancy can cause students to refer back to their answers on previous, similarly-worded items. Lederman et al. (1998) felt: “This cross-checking would result in inflated reliability estimates which could cause erroneous acceptance of the instrument’s validity” (p. 339).

Table 4.3
Descriptive Information for Each Scale in the Nature of Scientific Knowledge Survey, NSKS

Scale Name	Description	Sample Item
Amoral	Scientific knowledge provides man with many capabilities, but does not instruct him on how to use them. Moral judgment can be passed only on man’s application of scientific knowledge, not on the knowledge itself.	The applications of scientific knowledge can be judged good or bad; but the knowledge itself cannot.
Creative	Scientific knowledge is a product of the human intellect. Its invention requires as much creative imagination as does the work of an artist, a poet, or a composer. Scientific knowledge embodies the creative essence of the scientific inquiry process.	Scientific laws, theories, and concepts do **not** express creativity.
Development	Scientific knowledge is never ‘proven’ in an absolute and final sense. It changes over time. The justification process limits scientific knowledge as probable. Beliefs which appear to be good ones at one time may be appraised differently when more evidence is at hand. Previously accepted beliefs should be judged in their historical context.	Today’s scientific laws, theories, and concepts may have to be changed in the face of new evidence.
Parsimonious	Scientific knowledge tends toward simplicity, but not to the disdain of complexity. It is comprehensive as opposed to specific. There is a continuous effort in science to develop a minimum number of concepts to explain the greatest possible number of observations.	Scientific knowledge is stated as simply as possible.
Testable	Scientific knowledge is capable of public empirical test. Its validity is established through repeated testing against accepted observations. Consistency among test results is a necessary, but not a sufficient condition for the validity of scientific knowledge.	The evidence for scientific knowledge must be repeatable.
Unified	Scientific knowledge is born out of an effort to understand the unity of nature. The knowledge produced by the various specialized sciences contribute to a network of laws, theories, and concepts. This systemized body gives science its explanatory and predictive power.	Relationships among laws, theories, and concepts of science do **not** contribute to the explanatory and predictive power of science.

From Rubba & Anderson (1978, p. 456)

In light of the criticism aimed at the *Nature of Scientific Knowledge Survey*, I also used several open-ended response items from Lederman et al.'s (2002) *Views on Nature Of Science—VNOS* for triangulation purposes. The VNOS is discussed in the following section.

4.5.4 Views of Nature Of Science (VNOS)

To complement, expand, and add richness to the quantitative data generated from the *Nature of Scientific Knowledge Survey*, I used four open-ended response items from *Views of Nature Of Science, VNOS, Form C* (Lederman et al., 2002) in a pretest-posttest design. The VNOS includes 10 items, but I used only four items in order to triangulate results from other data sources. Figure 4.1 shows the four open-ended response items that I used (#1 and #2 were used in the spring of 2003, and #3 and #4 were used in the fall of 2003). The VNOS items were placed on the Science Education Department's website for one week. When I visited each of the 27 classes on the first day of SCED 401, I distributed the learning environment/attitude questionnaire and the *Nature of Scientific Knowledge Survey*, but also provided the website address to our department's homepage and explained how to complete the two VNOS items. Answering the VNOS questions served as a homework assignment and students were required to do this in their own time (pretest). During the last week of classes, I again visited each instructor's class but, this time, I set up a dozen laptop computers with Internet connections to enable students to answer the VNOS questions during that same day (posttest). Students' pretest and posttest responses were then matched and analyzed.

The four items from the VNOS were chosen because I felt that students' responses would correspond somewhat to scales on the *Nature of Scientific Knowledge Survey*, and this would allow a cross-check of understandings of that particular scale. For example, Item #2 in Figure 4.1 asks whether "scientists use their creativity and imagination during their investigations" and this corresponds fairly well to the NSKS scale of Creative. However, responses to Items #1 and #3 included some elements of Development and Testable on the NSKS, while Item #4 responses also included aspects of Development, particularly the notion that scientific knowledge is never 'proven' in an absolute and final sense.

Although there is some overlap, it is obvious that the developers of the *Nature of Scientific Knowledge Survey* and the *Views of Nature Of Science* had different interpretations of what is meant by ‘nature of science’. This is to be expected considering that there is 24-year time span between the two instruments. Even today, there is still some contention among philosophers, historians, sociologists of science, and science educators over specific issues and aspects regarding nature of science (Lederman et al., 2002; Schwartz et al., 2004). There is no singular nature of science and, therefore, no “agreement on what the phrase specifically means. Similar to scientific knowledge, conceptions of nature of science are tentative and dynamic” (Lederman et al., 2002, p. 499). As a result, any instrument will be biased toward the developers’ interpretation of the nature of science. The VNOS was developed with a postmodern view and based on eight generalized aspects of the nature of science that are relevant to K–16 education. These aspects include that: scientific knowledge is tentative, empirically-based, subjective or theory-laden, socially- and culturally-embedded, creative and imaginative, and the product of observations and inferences. It also involves theories and laws. The last aspect involves the lack of a universal recipe-like method for doing science. Schwartz et al. (2004) stress that none of these aspects can be considered apart from the others, and that there is not a one-to-one correspondence between a VNOS item and an aspect of the nature of science. Nevertheless, these aspects guided my analysis of the VNOS items that I used in my study, and they are discussed further in Section 4.8.5–Analyzing Views on Nature Of Science and in Chapter 6–Qualitative Results.

VNOS—Form C

1. What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?

2. Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?
   - ☐ If yes, then at which stages of the investigations do you believe scientists use their imagination and creativity: planning and design, data collection, after data collection? Please explain why scientists use imagination and creativity. Provides examples if appropriate.
   - ☐ If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if appropriate.

3. What is an experiment?

4. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with example.

Figure 4.1. Four of the possible ten questions from *Views of Nature Of Science, Form C* (VNOS-C) (Lederman et al., 2002)

Lastly, Lederman et al. (2002) and Schwartz et al. (2004) emphasize that the VNOS should be used in its entirety (i.e., all 10 items should be used), and then followed up by semi-structured interviews with respondents to verify and expand upon their understandings. (The VNOS is typically used with very small samples due to the amount of data generated from 10 open-ended response items.) As mentioned earlier, the VNOS was used as an additional data source in my study, rather than the primary source and, therefore, I made the decision to use only four of the 10 items. Although I did conduct interviews (see Section 4.6) with a subsample of the prospective elementary teachers (*n*=35), the purpose of the interviews was *not* to discuss the VNOS questions.

4.6 Interviews With Students in the Intervention Classes

Semi-structured interviews were conducted with 35 prospective elementary teachers in my two intervention classes during the last week of classes. The intervention classes consisted of all the classes of SCED 401 that I taught (six out of 27, or 22%) in which I integrated the Antarctic seabird data into the last third of the course. This was the time when students normally began work on an independent open-inquiry experimental design project, in the past, primarily in their own time. However, several years ago, I decided to involve a wildlife biologist/conservationist from the Biological Sciences Department of our college (both science education and biology are in the College of Natural Sciences and Mathematics) in helping me to improve the experimental design project. Together, we decided to use his dissertation data on Antarctic seabird chick growth rates as the basis for *all* the students' projects, to have him visit the class periodically, and to convert the project into a 'guided inquiry' (Colburn, 200) investigation with more in-class help from both of us. Consequently, the project also became an *authentic scientific inquiry* (Bell et al., 2003; Chinn & Malhotra, 2002; Roth, 1995; Ryder et al., 1999; Schwartz et al., 2004) because the students were using real scientific data and interacting with a scientist.

The semi-structured interviews occurred right after a short exit interview (an oral examination) that was already a regular component of SCED 401's assessment. Adding several more research questions, therefore, was not difficult or intrusive. Interviews were conducted in pairs in my office, and were audiotaped (after receiving verbal informed consent) for transcribing at a later date. In the past, I had found that conducting my exit interviews in pairs worked well, because it seemed that the students were not as nervous with this relatively new assessment strategy if a friend was sitting beside them. Participants were informed of the purpose of the interview, that participation was voluntary, and that responses would be kept strictly confidential. To ensure confidentiality and to encourage honesty and forthrightness, participants were identified by the last four digits of their student identification number.

A total of six questions were asked, alternating between the two participants. Consequently, each person usually answered three questions. If the second person (who was not answering a particular question) wished to comment, to add something different, to strongly agree or disagree, or to give another example, she was encouraged to do so. The interview took between 15 and 30 minutes. The questions focused on the research objectives of the study, and asked about differences between participants' previous laboratory course and SCED 401 with regard to cooperative learning groups, open-endedness, experiments and investigations, their attitude towards science. Other questions asked "when did you feel like a scientist during the Seabird Project" and if students had "any examples of an 'aha' moment during the project when they understood something about scientific work that they had not previously realized". The actual interview questions can be seen in Appendix C.

4.6 Concept Maps From the Intervention Classes–Nature of Science and the Seabird Project

Effective teachers can appreciate Richard Feynman's insight on learning: "The students had memorized everything, but they didn't know what anything meant" (Feynman, 1985, p. 192). Unfortunately, many of our prospective elementary teachers begin SCED 401 with the idea that rote memorization goes hand-in-hand with science learning. Every semester in SCED 401, I introduce students to concept mapping. Concept mapping is considered a metacognitive tool (i.e., thinking about one's own thinking), cognitive roadmap, and graphical representation of students' thinking and understanding on a particular topic and set of concepts (Duit & Treagust, 1995; Novak, 1990; Novak & Gowin, 1984; Roth, 1995; White & Gunstone, 1989, 1992). The basic idea of a concept map is that students first make a list of key concepts on a topic and then arrange them to show hierarchical relationships (if they exist) and interrelationships. At the beginning of the semester, I usually have students write the concepts on small pieces of paper about five centimeters by five centimeters, and then they can physically move the concepts around and, when satisfied, glue the concepts into their scientific notebooks. Thus, this becomes a hands-on activity as well as a metacognitive tool. Linking words (prepositions) are drawn on arrows or lines connecting concepts. Although not all instructors insist on linking words or a hierarchical system, I have found these two elements of a concept map crucial to accurately tapping into students' understanding.

Novak and Musonda (1991) and Novak and Gowin (1984) conducted many studies on the effectiveness of concept maps constructed by individuals. In my SCED 401 intervention classes, concept mapping is practiced both individually and in collaborative groups throughout the semester as we proceed through various units. Other researchers (Roth, 1995; Roth & Roychoudhury, 1992, 1993a, 1993b, 1994a) have recognized the potential of concept maps for engaging students in collaborative "science talk" in which "concept maps and the talk through which they are constituted are in a reflexive relationship" (Roth, 1995, p. 96). Like the researchers above, I too, have concept mapping follow all other activities in a particular unit, to serve as a capstone exercise allowing students to integrate everything that they have learned in the unit. In summary, I feel concept mapping is an effective science teaching and learning strategy, particularly for understanding the nature of science. I have five reasons for saying this:

1. Concept mapping allows instructors to easily see students' preconceptions and misconceptions on a particular topic.
2. Concept mapping promotes meaningful learning.
3. Concept mapping can help achieve understanding of the tentative of science (one of Lederman et al., 2002, aspects of the nature of science).
4. Concept mapping facilitates cooperative learning.
5. Concept mapping promotes metacognition.

During the final written examination in my SCED 401 classes, I have students construct a concept map based on the following prompt:

> *Construct a concept map using 15 concepts or phrases that illustrate your understanding of the nature of science as it relates to the Antarctic Seabird Project. Make sure you use linking words between your concepts.*

Roth (1995) criticizes the notion that concept maps can be used as a device to evaluate student understanding. He states that concept maps "…represent only a very meager slice of what students know" and that "concept maps are not convenient hard copies of students' frameworks, but momentary constellations fixed in the course of situated interactions" (p. 80). Nevertheless, during the fall semester of 2002 and spring semester of 2003, I collected five sample concept maps to analyze for my study. These maps were selected because they represented what I described as 'good, average/medium and poor' examples of a synthesis between the nature of science and the Antarctic Seabird Project. Albeit only a meager slice or a stroboscopic-like snapshot (Treagust, Duit, & Fraser, 1996), these concept maps do help answer part of Research Question #4: *How does integrating real research data on Antarctic seabirds affect prospective elementary teachers' understandings of the nature of science?*

Further details of my analysis are described in Section 4.8.6–Analyzing Information From Interviews and Concept Maps, while the students' concept maps and the results of my analysis are in Chapter 6–Qualitative Results.

4.8 Methods of Data Analysis

The following six sections describe how I analyzed my data. Section 4.8.1 describes how I validated the science learning environment and attitude questionnaire and the *Nature of Scientific Knowledge Survey*. Section 4.8.2 describes how I explored differences between prospective elementary teachers' previous laboratory courses and SCED 401 in terms of the learning environment, attitudes towards science, and understandings of the nature of science. Section 4.8.3 describes analyses for differences between the intervention (received Antarctic seabird data for experimental design project) and nonintervention classes (did not receive Antarctic seabird data, but instead chose their own 'open inquiry' project) in relation to the same three variables. Section 4.8.4 discusses methods for investigating associations between the learning environment and the student outcomes of attitude and understandings of the nature of science. Section 4.8.5 deals with the analytic induction and comparative method procedures used for the online qualitative survey, *Views of Nature Of Science, VNOS.* Lastly, how I analyzed the interviews with students in the intervention classes (*n*=35) and the concept maps (*n*=5) are described in Section 4.8.6.

4.8.1 Validating the Science Learning Environment and Attitude Questionnaire and the Nature of Scientific Knowledge Survey

Although all eight items from the four scales of the WIHIC and all seven items from the two scales of the SLEI were used, the new combination of 46 items that comprised the questionnaire for this study needed to be validated. Thus an exploratory factor analysis (Coakes & Steed, 2003) on scores for students' previous laboratory class and for SCED 401 were conducted on the six scales to provide an indication of its overall structure. In addition, because this study was the first to investigate perceptions of prospective elementary teachers in a science laboratory course, it was important to analyze the survey's structure with this new population.

The exploratory factor analytic procedure consisted of three steps: (1) computation of the correlation matrix which determined the appropriateness of the factor analytic model, (2) factor extraction using principal axis factoring (PAF) which determined the number of factors or scales necessary to represent the data, and (3) varimax rotation which made the factor structure more interpretable (Coakes & Steed, 2003, p. 147). During varimax rotation, items were omitted if they had factor loadings less than 0.40 as recommended in many previous learning environment studies (Adolphe et al., 2003; Aldridge & Fraser, 2000; Lightburn & Fraser, 2002; Majeed et al., 2002; Sinclair & Fraser, 2002; Soto-Rodriquez & Fraser, 2004; Wong et al., 1997; Zandvliet & Fraser, 2004). One major assumption of conducting an exploratory factor analyses is that a suitable sample size has been used. Coakes and Steed (2003) state that "a minimum of five subjects per variable is required…" (p. 147). With 46 items in my science learning environment survey, at least 230 subjects were needed. This study had over double this amount (*N*=525). Lastly, the percentage of variance for each scale and the total variance were reported, along with eigenvalues for the different scales.

A second exploratory factor analysis was conducted for the *Nature of Scientific Knowledge Survey,* NSKS. Rather than using a factor loading of 0.40 as the cut-off point, factor loadings of less than 0.30 were omitted during the item analysis of the NSKS. The percentage of variance and eigenvalue for each of the scales, as well as the total variance, were reported. Further details of the factor and item analysis for both the science learning environment scales and for the NSKS are provided in Sections 5.2 and 5.4 in Chapter 5–Quantitative Results.

4.8.1.1 Individual Versus Class Mean as the Unit of Analysis

Stern et al.'s (1956) distinction between *private* beta press and *consensual* beta press comes into play when considering the level or unit of statistical analysis (Fraser, 1986b). Private beta press is most appropriate when a study focuses on individuals within a class, such as in case studies. Consensual beta press recognizes the class as a whole, and is appropriate in studies investigating the effects of curricular reforms, interventions (e.g. the Antarctic seabird data used in my classes), and new teaching strategies. Consensual press "yields generalizations about the average effects of class characteristics upon a group of students as a whole", but "gains in objectivity and generalizability…need to be weighed against the potential loss of information about individual students within a class" (Fraser, 1986b, pp. 10-11). Throughout my quantitative data analyses, I used the individual as the unit of analysis (i.e., a between-student analysis) and/or the class mean as the unit of analysis (i.e., a between-class analysis), depending on the nature of my research question. For example, for Research Question #1: *Is it possible to develop valid and reliable measures of prospective elementary teachers' perceptions of the learning environment, attitudes towards science, and understandings of the nature of science?* I used the individual as the unit of analysis for the factor analysis of the learning environment/attitude questionnaire and the *Nature of Scientific Knowledge Survey.* This decision was made based on my adequate sample size of 525, whereas 27 classes were not sufficient to conduct a meaningful analysis based on the class mean as the unit of analysis.

4.8.1.2 Internal Consistency Reliability, Discriminant Validity, and Ability to Differentiate Between Classrooms

Coakes and Steed (2003) report that factor analysis and reliability are complimentary procedures in scale construction and definition. Good internal consistency ensures that the items comprising each factor produce a reliable scale and that each scale yields the same results each time it is administered (Anderson, 1998). Although there are a number of different reliability coefficients, one of the most commonly used is Cronbach's (1950) alpha (Coakes & Steed, 2003). Cronbach alpha is based on the average correlation of items within a scale when the items are standardized. Values range from zero to one. In my study, only items from the learning environment scales that had factor loadings of 0.40 and greater, for either previous laboratory courses and/or SCED 401, were retained when determining the internal reliability. In calculating the NSKS' reliability, items with factor loadings of 0.30 and greater for the pretest and/or the posttest were used. Cronbach alpha reliability coefficients were reported for the learning environment and attitude scales for previous laboratory classes and for SCED 401, for two units of analysis (individual and class mean). Cronbach alpha coefficients were also reported for the pretest and posttest scores on the *Nature of Scientific Knowledge Survey.*

Validity refers to the extent to which what we measure accurately reflects what we expected to measure (Anderson, 1998). Discriminant validity is the degree to which a scale measures an intended hypothetical construct and no other construct. Discriminant validity of the science learning environment questionnaire and the NSKS were reported using the Pearson product-moment correlation coefficient (Coakes & Steed, 2003). Thus the mean correlation of one scale with the remaining five scales on the learning environment questionnaire was calculated. As with the test for internal consistency reliability, discriminant validity was determined for students' previous laboratory courses and SCED 401 with regard to the learning environment, while mean correlations with other scales were reported for the pretest and posttest for the NSKS, for two units of analysis.

4.8.1.3 Ability to Differentiate Between Classrooms With Regard to Learning Environment

To further check the validity of the learning environment scales, a one-way ANOVA was used to indicate whether each scale differentiated significantly between perceptions of prospective elementary teachers in different university classrooms. Theoretically, students within the same class should perceive the class similarly, while mean within-class perceptions should vary from class to class. The eta^2 statistic, which is the ratio of 'between' to 'total' sums of squares, indicates the proportion of variance explained by class membership. It would be expected that the eta^2 statistic for previous laboratory classes would not be as strong as for SCED 401. This is because a greater degree of variability exists between previous laboratory courses. As mentioned earlier, students' previous laboratory course was likely one of the prerequisite science courses (Biology, Physical Science, or Geology), but students had a wide variety of instructors and some students took their prerequisite courses at a junior college before transferring to California State University, Long Beach.

4.8.1.4 Validating the Attitude Scale

An estimate of the internal consistency reliability of the Enjoyment of Science Lessons scale extracted from the TOSRA (Fraser, 1981) was made using the Cronbach alpha coefficient for both previous laboratory classes and SCED 401, and for two units of analysis (individual and class mean).

Further details of the internal consistency reliability of the learning environment and attitude scales and of the *Nature of Scientific Knowledge Survey*, the discriminant validity of the learning environment scales and NSKS, and the ability of the learning environment scales to differentiate between classrooms can be found in Chapter 5–Quantitative Results.

4.8.2 Exploring Differences Between Students' Previous Laboratory Courses and SCED 401 in Learning Environment and Attitudes, and Differences Between Before and After SCED 401 for Nature of Scientific Knowledge Survey

Descriptive statistics were used to compare the students' perceptions of the learning environment and attitudes towards science during their previous laboratory course and SCED 401, using the class mean as the unit of analysis. During the data collection period, 27 classes were involved in the study. The same procedures were used to examine differences between students' understandings of the nature of science before SCED 401 began based on their overall science education experience and not just one course (pretest), and after completing SCED 401 (posttest). Descriptive statistics included the average item mean for each scale (scale mean divided by the number of items in that scale) and the average item standard deviation. The average item mean was used because this allowed meaningful comparisons between scales with differing numbers of items (WIHIC had 8 items, and SLEI had 7 items).

I also calculated the effect size (Cohen, 1988; Thompson, 1998, 1994) of any differences with regard to learning environment and attitude. The effect size reveals the magnitude of a difference, and was calculated by dividing the difference between the means for previous laboratory courses and SCED 401 by the pooled standard deviation. The same procedure was repeated for understandings of scientific knowledge–the difference between the pretest and posttest means divided by the pooled standard deviation. Because I used the class mean as the unit of analysis (consisting of 27 classes), standard deviations are expected to be small and effect sizes, therefore, large. Effect sizes are generally not expected to be large, however, in the behavioral sciences (Cohen, 1988, p. 284). Cohen states that an effect size of 0.10 and less is considered small, 0.25 is a moderate effect size, and 0.40 and above indicates a large effect size. In contrast, Royer (2000) cautions: "It is important to note that measures of effect sizes do not directly translate into indications of practical importance" (p. 239). Over 20 years ago, Glass, McGaw, and Smith (1981) stated the following.

> There is no wisdom whatsoever in attempting to associate regions of the effect-size metric with descriptive adjectives such as "small," "moderate," "large," and the like. Dissociated from a context of decision and comparative value, there is no inherent value to an effect size of 3.5 or 0.2. (p. 104)

A *t*-test for paired samples was calculated for each of the 11 scales to determine the statistical significance of any differences between students' previous laboratory course and SCED 401, and between understandings of the nature of science before SCED 401 and after SCED 401. A *t*-test for paired samples is also called a repeated-measures *t*-test or dependent-samples *t*-test (Coakes & Steed, 2003). For my study, I had data from only one group of participants (i.e., prospective elementary teachers), but each individual and each class had two scores under different conditions of the independent variable–the learning environment of students' previous laboratory course and SCED 401. "Data that are collected from the same group of participants are also referred to as within-subjects, because the same subject performs in both conditions" (Coakes & Steed, 2003, p. 68).

Because multiple *t*-tests were conducted and the possibility of a Type I error existed (differences appear statistically significant but might not be in reality), a modified Bonferroni procedure was conducted as well (Holland & DiPonzio Copenhaver, 1988; Jaccard & Wan, 1996). This procedure guards against error inflation and results in a more conservative measure of statistical significance. The modified Bonferroni procedure involved ranking the *t*-values from most significant to least significant, and dividing the most significant *p*-value by the total number of tests performed (*n*). In my study, 11 tests were conducted. If the resulting *p*-value is less than the desired alpha (0.05 or 0.01), the difference is still considered significant. The second difference is considered significant if the resulting *p*-value is less than the desired alpha after dividing by *n*–1. This procedure is continued for each successive *p*-value by dividing by *n*–*k* until a statistically nonsignificant result is obtained, thereby guaranteeing that the remaining values are also not significant. Section 5.6 in Chapter5—Quantitative Results report the results of the modified Bonferroni procedure.

4.8.3 Exploring Differences Between Intervention and Nonintervention Classes for Learning Environment, Attitudes and Nature of Scientific Knowledge Survey

As discussed in Section 4.6, the intervention classes of SCED 401 (i.e., 6 of the 27 classes) had the wildlife biologist's Antarctic seabird data with which to work during their experimental design project. In the nonintervention classes, students chose their own project, worked individually, and completed the majority of the investigation at home in their own time. The intervention classes' data consisted of the chick growth rates of four species of petrel (a seabird related to the albatross) based on four anatomical features–mass, tarsus or leg, culmen or beak, and wing–which were collected over two field seasons in Antarctica. Students could choose one or more of these variables, one or more of the four petrel species, and one or both seasons when data were collected in order to make comparisons and investigate relationships. As such, these combinations provided many possibilities for unique research questions for the six groups in each class. Although in-class work was done in groups of four or five students, final reports on the Seabird Project were done in groups of two or three individuals. The most noteworthy aspect of this project was that it was based on actual scientific data and, therefore, can also be called *authentic scientific inquiry* (Bell et al., 2003; Chinn & Malhotra, 2002; Roth, 1995; Roth & Roychoudhury, 1993; Ryder et al., 1999; Schwartz et al., 2004). The Seabird Project's overall purpose, in fact, was to increase the authenticity and sophistication of the students' experimental design project and, as a consequence, to improve their understandings of the nature of science and of what actual scientists do in their work (a major goal of the course). Each semester, I taught two classes of SCED 401, and both received the intervention. About the last one-third of the semester was spent entirely on the Seabird Project.

Descriptive statistics (i.e., average item means, standard deviations, and effect sizes) were determined for the six intervention and 21 nonintervention classes of SCED 401 for all 11 scales, using the class mean as the unit of analysis. Effect sizes were calculated in the same manner as described earlier.

A *t*-test for independent samples was calculated to determine whether differences between the scores of the intervention and nonintervention classes were statistically significant. "An independent groups *t*-test is appropriate when different participants have performed in each of the different conditions–in other words, when the participants in one condition are different from the participants in the other condition. This is commonly referred to as a between-subjects design" (Coakes & Steed, 2003, p. 70). In my study, only my students received the intervention, while the students in the other instructors' classes (i.e., 21 classes) did not receive the intervention. Although multiple *t*-tests were conducted, a modified Bonferroni procedure was not applied because the subsample of six 'intervention' classes was considered too small for this procedure.

4.8.4 Associations of Learning Environment With Attitudes and Understandings of the Nature of Science

To investigate associations between the learning environment and the student outcomes of attitudes towards science and understanding of the nature of science, simple correlation and multiple regression analyses were carried out, using both the individual and class mean as the units of analysis. Simple correlations reveal the bivariate association between the dependent variables of attitudes and understandings of the nature of science and each of the six learning environment scales (but does not hold the other five scales constant). The multiple correlation analysis provided a test of the combined influence of the six independent learning environment variables on attitudes and the nature of science. This analysis provided simpler information about learning environment-attitude and learning environment-nature of science associations, and reduced the risk of a Type I error often linked with simple correlation analysis.

To determine which specific learning environment scales accounted for most of the variance in the attitude and NSKS scales, standardized regression weights were examined. The regression coefficient indicates the strength of the association between each learning environment scale and an attitude or NSKS scale when the five other learning environment scales are mutually controlled.

4.8.5 Analyzing Views of Nature Of Science, VNOS–Online Survey

The previous sections in this chapter provided details about how I analyzed the quantitative data derived from the science learning environment and attitude questionnaire and the *Nature of Scientific Knowledge Survey*. This section describes how I analyzed the qualitative data generated from *Views on Nature Of Science, VNOS* (Lederman et al., 2002), an open-ended response questionnaire given to students during the spring and fall semesters of 2003. The VNOS data were used to triangulate quantitative results whenever applicable, to add richness and depth to my study, and to help to answer my research questions based on another data source. Although I did not use the VNOS exactly as the developers had intended (e.g., I neither used all 10 items nor conducted interviews to verify respondents' answers), the VNOS items chosen did correspond somewhat to the scales on the *Nature of Scientific Knowledge Survey*.

Lederman et al. use the VNOS with very small samples, and they categorize participants' responses as either naïve, informed, or no category. However, I found this classification system restrictive and, therefore, I expanded my analysis of each item well beyond the three-category system. Nevertheless, throughout my analysis, I was guided by Lederman et al.'s (2002) earlier work, particularly their identification of misconceptions, in order to identify patterns and connecting threads between all the VNOS responses.

For each VNOS item, I produced an analytical chart or typology (Erickson, 1998) that provided a summary of the frequency and type of perspectives and beliefs represented in the students' responses. In addition, through an analytic inductive (Lindesmith, 1947) or recursive process (Erickson, 1998), I identified both typical and atypical quotes as evidence for the claims and assertions made throughout my narrative, hopefully avoiding what Erickson describes as "one-dimensional and superficial" (p. 1167) writing. Three types of text were used throughout my narrative as recommended by Erickson (1998). These included *particular descriptions* that provided detailed evidence (i.e., quotes) for claims, *general* *descriptions* that showed patterns of generalizations within a case, and *orienting commentary* that included interpretive or theoretical comments to try to explain why students said what they said, and to serve as a 'road sign' for the reader. Good qualitative data analysis reveals patterns in the forest but allows the reader to become familiar with a few trees as well (Erickson, 1998, p. 1169).

Section 4.8.5.1 describes how I recorded and analyzed the data for the VNOS items in the spring semester of 2003, while Section 4.8.5.2 discusses the data from the fall of 2003.

4.8.5.1 VNOS Items–Spring 2003

As described in Section 4.5.4, students responded to two VNOS items online in the spring of 2003. During the pretest, students answered the items during the first week of classes as a homework assignment. The link to the VNOS items, located on the Science Education Department's homepage, was removed after one week so that responses were not influenced by activities, lectures, and discussions in the SCED 401 classes. During the last week of classes and 15 weeks later, I visited all 27 classes and set up laptop computers with Internet connections. This allowed students to respond to the VNOS items on the same day when they completed their science learning environment and attitude questionnaire and the *Nature of Scientific Knowledge Survey*. All VNOS pretest and posttest responses were saved in a document file for each semester. Responses were identified only by the student's campus identification number, their email address, and their SCED 401 instructor's name.

Although very tedious and unsophisticated, all responses from each semester were printed out, and then our SCED 401 laboratory student assistants individually separated them with scissors so that pretest responses could be paired with posttest responses by matching the student's identification number. Naturally, the pretest response rate was not as good as for the posttest and, as a result, only 115 matches for the spring 2003 semester and 98 matches for the fall 2003 semester were made. Nevertheless, these numbers provided ample data for analysis and identification of themes, patterns, and connecting threads.

From the two VNOS items answered in the spring of 2003, only one was analyzed. Item #1 *What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?* was not analyzed because of time constraints, and because a preliminary 'read-through' of responses indicated that it did not correspond closely to any of the NSKS scales. Only Item #2 responses on whether *'scientists use their creativity and imagination during their investigations'* (see Figure 4.1 for complete wording of this item) were recorded and analyzed by an analytical inductive process (Erickson, 1998; Lindesmith, 1947) and constant comparative method (Glaser & Strauss, 1967).

Once the SCED 401 laboratory assistants had matched the pretest and posttest responses and organized them by instructor, I entered key phrases or sometimes entire responses from the *pretest* directly into an Excel spreadsheet. From my quantitative data-collection procedures, I already had a record of students' identification numbers organized by instructor's name. I recorded phrases/responses of all 115 students and did not read the posttest responses so that I would not be influenced or biased by their later response.

Item #2 was fairly straightforward to analyze and I was able to produce an analytical chart/tabulation that summarized the responses. Erickson (1998) points out that "…good qualitative research reports the range and frequency of actions and meaning of perspectives that are observed, as well as their occurrence narratively" (p. 1155). Thus, I calculated how many of the 115 students said 'yes, creativity and imagination are needed for investigations' and how many said 'no, creativity and imagination are not needed for investigations'. I paid particular attention to atypical or discrepant responses (Erickson, 1998) and included them as quotes followed by my narrative. In addition, I recorded how many students said creativity and imagination are only needed during the planning and design stage (the most common response from naïve nature of science learners according to Lederman et al., 2002), how many said two out of the three stages, and how many said all three stages–planning and design, data collection, after data collection–require creativity and imagination. Sample representative quotes were extracted and I provided a commentary around the quotes. Erickson (1998) describes this as "assertive writing or executive commentary" (p. 1171) because the researcher must lead the reader's attention through the text as details in quotes often do not speak coherently to the reader. This same procedure was carried out for the posttest responses and, finally, I calculated the differences in percentage between the various types of pretest-posttest responses.

4.8.5.2 VNOS Items–Fall 2003

For the fall 2003 semester, students responded to Item #3 *What is an experiment* and Item #4 *Is there a difference between a scientific theory and a scientific law*? The same procedure described in the above section for the item in spring 2003 was followed. For each question, a summary analytical chart was produced. I recorded phrases or entire pretest responses from the 98 students, and then analyzed the pretest responses to generate frequency reports. This was followed by recording and analyzing the posttest responses, and then comparing differences in pretest-posttest responses. Lastly, representative quotes served as evidence throughout my narrative.

Item #3 *What is an experiment* required more in-depth analysis than Item #2. I had to review the responses several times, and make modifications to the phrases that I had recorded earlier on in the Excel spreadsheet. Eventually, I proposed five tentative *assertions* or *themes* (Anderson, 1998; Creswell, 1994; Erickson, 1998; Glaser & Strauss, 1967) in which to categorize the students' responses. Because this process was more subjective than the analysis involving Item #2, I went through the recursive process of reviewing and revising many times. Even when I had decided on the five assertions/themes, I categorized the 98 responses twice and took the average of the two 'trials' to record in my analytical chart.

Item #4 *Is there a difference between a scientific theory and a scientific law?* produced responses that were again fairly straightforward and less ambiguous than the responses for Item #3. After an analytical chart was produced, quotes were extracted and organized in a logical, coherent fashion throughout the text.

4.8.6 Analyzing Information From Interviews and Concept Maps

The last two qualitative data sources included interviews with students and concept map tests from the intervention classes. Section 4.8.6.1 describes how I analyzed the interviews, and Section 4.8.6.2 describes how I analyzed the concept maps.

4.8.6.1 Analyzing Interviews With Students in Intervention Classes

As described in Section 4.6, 35 female prospective elementary teachers were interviewed in pairs after the exit interview/oral examination during the fall semester of 2003. Each student answered at least three of the six interview questions (see Appendix C) although, if time permitted and if a student seemed eager to volunteer information, this number was exceeded. The questions were generated after consultation with our Science Education Department Chair, who has considerable experience with qualitative studies, particularly those that involve interviews. Although the six questions were fairly structured and closely tied to my study's research questions, I did ask additional questions occasionally when a student offered an interesting perspective or comment, or when a statement needed clarification. The students were informed that participation was voluntary and that their responses would be anonymous and confidential. Only one of my female students decided not to participate in the interview. Throughout the interview, students were referred to by their university identification number. I hoped that this would also encourage the prospective elementary teachers to be honest and forthright, and not just tell me what they thought that I wanted to hear. Interviews were conducted in my office and audiotaped (once I received verbal permission) for later transcribing (Fontana & Frey, 1998; Miles & Huberman, 1994; Seidman, 1991).

Using a conventional transcribing machine, the interviews were transcribed word-for-word several months after the end of the semester. Over 100 pages of double-spaced text resulted. I read and reread the pages many times until I tentatively proposed five themes (Anderson, 1998; Creswell, 1994; Seidman, 1994) that seemed to emerge from the students' responses. In generating themes, Seidman recommended focusing on comments dealing with conflict, frustrations, or other intense emotions. Erickson (1998) stresses that qualitative research is inherently tentative and an ongoing construction and, therefore, "it is not the reality it attempts to represent" (p. 1167). Consequently, the themes were modified several times, but still mirrored the original questions that I had asked. One question, however, asking about investigations and experiments in previous laboratory courses compared to SCED 401, was subsumed in responses to the other five questions. Whenever possible, I tried to make themes as descriptive as possible to provide a 'road sign' or 'foreshadow' (Erickson, 1998) for the reader.

Once I decided on the themes, I went through the text again and used a different-colored highlighting marker to identify relevant text pertaining to each of the themes. Several 'frequency of responses' were recorded for the interviews but not as many as was done for the VNOS items. From the highlighted text, I sifted out sections that seemed more compelling from sections that were of less interest, thereby reducing the data inductively (Seidman, 1991, p. 89) or, as Erickson eloquently says: "To draw is to leave things out" (1998, p. 1162). This reflective analysis was part of a dialectical process in which the prospective elementary teachers had spoken, I responded to their words, and I then concentrated my intuition and intellect on the process of synthesizing what they had said (Anderson, 1998; Seidman, 1991).

In moving from the selected sections of the highlighted text to placing quotes in a logical sequence in my study, I was faithful to the words of the prospective elementary teachers (even if they possessed poor grammatical skills). I only had to decide where periods, commas and other punctuation marks went, and then delete a few 'uhms' and 'you knows' and other idiosyncrasies that the person would not use in writing. I also inserted transitional and/or clarifying words or phrases occasionally and these were placed in italics and square brackets. Lastly, in writing my narrative around the quotes, I was guided by Erickson's (1998) explanation of the three types of text in qualitative research writing–particular description, general description, orienting commentary–which I discussed in Section 4.8.5.

4.8.6.2 Analyzing Concept Maps From Students in the Intervention Classes

As described in detail in Section 4.7, concept maps were analyzed from five students in two of my intervention classes (fall 2002 and spring 2003 semesters). The concept maps were produced as part of their final written examination and followed a full semester of practice in concept map construction, both individually and in groups. The purpose of the concept map was for the student to show me how the Seabird Project helped them understand the nature of science. All eight aspects of the nature of science as proposed by Lederman et al. (2002) (along with other features related to a wildlife biologist's fieldwork) had been discussed throughout the semester in both an implicit and explicit fashion, and also during reflective discussions and written exercises. The five concept maps were chosen because they represented what I felt were 'good, average or medium, and poor' syntheses of ideas/topics from the Seabird Project with the nature of science.

Students' paper-and-pencil concept maps were converted to an electronic format using the software program called 'Inspiration'. No changes or improvements were made to the concept maps. My analysis consisted of an explanation of why I felt that each concept map was good, average or poor. This was predominantly based on how many of the nature of science aspects or other features were mentioned along with the use of examples from the Seabird Project. Novak and Gowin (1984) proposed a method for scoring concept maps by counting the number of links and cross-links, but my focus was not on concept map construction per se, but rather on content and synthesis.

4.9 Limitations of Methods

Critics of quantitative research methods would say that the use of forced-choice, convergent paper-and-pencil questionnaires provide only a broad overview of science teaching and learning, and reflect the developers' biases and interpretations (Lederman et al., 1998). There is no guarantee that respondents understand the meaning of survey items exactly as the developers intended, or that they are attentive and honest about their responses. Students completed the survey on the first day of classes.using a 'retrospective' approach whereby they reported their perceptions of the learning environment and attitudes towards science based on their previous laboratory course. For some, memories might have faded over time and this could have affected their responses. Also, because I visited students during the last week of classes to administer the survey for a second time, it is possible that their stress levels were higher than usual (due to final papers and upcoming examinations), and that they did not take as much care in completing the questionnaires as they did at the beginning of the course. However, the modified learning environment and attitude questionnaire used in my study is based on *What Is Happening In this Class?* and the *Science Laboratory Environment Inventory,* and both have proven to be highly valid and reliable with thousands of students in elementary, secondary and university levels, in many countries of the world, and across a wide range of subjects (Aldridge et al., 1999; Chionh & Fraser, 1998; Dorman, 2003; Fraser et al., 1992a, 1992b, 1993, 1995; Giddings & Waldrip, 1996; Hofstein et al., 2001; Kim & Kim, 1995, 1996; Margianti et al., 2002; Moss & Fraser, 2002; Pickett & Fraser, 2004; Raaflaub & Fraser, 2002; Riah & Fraser, 1998; Seopa et al., 2003; Zandvliet & Fraser, 1998, 2004). Assessing psychosocial perceptions of the learning environment through such instruments provides an accurate picture of what is truly happening within the walls of a classroom. Rigorous statistical procedures and a relatively large sample size add strength to my study's methodology.

On the other hand, because my study was not an 'experimental' study, many variables could not be controlled. There is always the ever-present possibility of extraneous variables that could have effected my results. Examples of some of these extraneous variables include the mood, fatigue or anxiety level of the prospective elementary teachers when completing questionnaires, participating in interviews, or constructing concept maps during an examination, self-efficacy related to learning science in general and teaching elementary school science in particular, lack of a set curriculum, class sizes ranging from 14 to 32 students, instructors' teaching experience and skill, and instructors' conviction about the importance of establishing a positive learning environment, and on covering the course syllabus and goals adequately. With regard to my correlational results, potential problems are that traditional correlation methods assume linear relationships between variables, and that correlation does not establish cause-and-effect relationships (Anderson, 1998).

One variable that I did control—gender—could be viewed as both a strength and a limitation of my study. I felt that not considering males' responses in my data analysis would be an advantage because elementary teacher education programs throughout the California State University system are dominated by female students. I wanted my findings to be applicable to other campuses across the state university system and, hopefully, to other colleges and universities across the state and country as well.

A major limitation with regard to my qualitative data-gathering methods and analyses is a possible lack of researcher objectivity and internal or face validity (i.e., 'trustworthiness', Denzin & Lincoln, 1994; Grundy, 1995; Lincoln & Guba, 1985). I am the researcher, but I was also the instructor for six of the 27 classes of SCED 401 in which integration of the Antarctica seabird data occurred. Critics could say that I had a personal stake in the results when I was analyzing data from the open-ended VNOS items, the interviews with students in my intervention classes, and the concept maps. Content analysis has the limitation of counting and recording data that are there and rarely what is missing (Anderson, 1998). Results are always subject to other interpretations. However, I paid attention to unusual and atypical responses and recorded them in my text. I was not afraid to mention negative events that occurred in my classroom such as the tensions and arguments that occurred in a couple of the groups (discussed in Chapter 6–Qualitative Results). With regard to the VNOS item analysis, responses did not come from just my classes. Six other SCED 401 instructors had students answer the VNOS questions (and one instructor had two or three classes every semester). Ideally, it is desirable to have additional researchers involved in a study to establish inter-rater reliability, which would have been particularly helpful for the analysis of VNOS responses and interviews. However, this is rarely possible during a doctoral thesis. Instead, I triangulated data generated from various sources, using both between-methods and within-methods approaches, and also I tried to incorporate a 'chain-of-evidence', an interconnected path of evidence leading from one data source to the next (Anderson, 1998).

A second limitation of my qualitative methodology is "the reliability of informants' information…the relationship of the informant to the researcher all tend to color the interpretation of data" (Anderson, 1998, p. 133). This is, in fact, a serious concern because 22% of the informants (i.e., all the prospective elementary teachers in the intervention classes) were my own students. During the interviews with 35 students, they might have felt that their letter grade was at stake, and that they should tell me what they think that I wanted to hear. "People typically provide socially acceptable responses which are *[may]* not *[be]* valid. About five percent may lie in response to factual questions: 'Do you own a car?'" (Anderson, 1998, p. 165). However, I tried to guard against this by referring to the students during the interview by the last four digits of their university identification number. Also, because of the personal nature of the course itself, with lots of classroom discussion and interaction encouraged, I get to know my students quite well, and often on a personal level. Throughout the course, I encourage honesty and continually say that it is quite alright to disagree with the teacher, an article or book, or to dislike science or a science teaching method. Hopefully, this attitude on my part encouraged students to be candid during the interviews.

Another important consideration with regard to my methodology is that all of my classes received the intervention. No other classes of SCED 401 taught by another instructor had the opportunity to use the Antarctic seabird data for their students' experimental design projects. Part of the intervention was also having the wildlife biologist visit the class periodically during the last one-third of the course, and it was not possible for him to visit additional classes because of his other teaching and research responsibilities. One could argue that any effects, whether positive or negative, between the intervention and nonintervention classes had nothing to do with the intervention per se. Naturally, I cannot argue that my classes were exactly the same as the nonintervention classes with the one exception of having the Antarctic seabird data integrated into the class. Perhaps positive effects could be due to having two instructors involved in the course, and negative effects could be due to the elimination of choice in the experimental design project, for example.

Lastly, because this was an evaluative and descriptive study of a unique and innovative course, including the evaluation of a somewhat unusual intervention, findings from my study might not be generalizable to a broader group of prospective elementary teachers. Most elementary teacher education programs do not have a course like SCED 401–colleges and universities feel that one or two traditional science content courses and a science methods course are adequate. SCED 401, however, could serve as a model for other institutions and as a blueprint on how to design a hands-on guided/authentic scientific inquiry course for prospective elementary teachers.

4.10 Summary of Chapter

This chapter described the quantitative and qualitative methods which I employed in my study. I used both between-methods and within-methods to triangulate my data from multiple sources. In Section 4.2, I described the participants (*N*=525 students in 27 classes) involved in the quantitative probe assessing perceptions of the science learning environment, attitudes towards science, and understandings of the nature of science. Section 4.3 described my role as researcher in the study, and also as one of the seven instructors. Section 4.4 described the four questionnaires that I used, namely, the *Science Laboratory Environment Inventory, What Is Happening In this Class?, Test of Science-Related Attitudes,* and *Views of Nature Of Science–Form C.* Two scales from the SLEI (Open-Endedness and Material Environment) and four scales from WIHIC (Student Cohesiveness, Instructor Support, Investigation, and Cooperation) were used to assess the learning environment in the hybrid laboratory/seminar science course called *A Process Approach to Science* (SCED 401), that was specifically designed for prospective elementary teachers. One scale from the TOSRA (Enjoyment of Science Lessons) was used to measure attitudes towards science. Perceptions of the learning environment and attitudes towards science were assessed based on the students' *previous* laboratory course, usually a prerequisite science course. Perceptions of and attitudes during previous laboratory courses were then compared to perceptions and attitudes towards science at the end of SCED 401. Understandings of the nature of science were measured by the NSKS in a pretest-posttest design (the pretest was based on students' *overall* science education experience and not just one course), and by using open-ended response items from VNOS. Not all 525 prospective elementary teachers completed the VNOS questions, however. The number of matches that were made between pretest and posttest responses was 115 in the spring of 2003 and 98 in the fall of 2003.

Section 4.6 described the interviews that I conducted with students (*n*=35) in two of my intervention classes. The intervention classes received the Antarctic seabird data to use during their experimental design project. Nonintervention classes conducted an open-inquiry project of their own choosing, but mainly conducted in students' own time. The Seabird Project was an in-class, guided-inquiry project and a scientifically-authentic investigation into chick growth rates in Antarctica based on four anatomical features, four species of petrels, and two seasons of field work. The purposes of the interviews were to add depth and richness to the quantitative findings, to triangulate data, and to uncover patterns in the forest, but also to become familiar with individual trees as well (Erickson, 1998).

Section 4.7 described concepts maps that were collected and analyzed from five students in my intervention classes. The purpose of the concept maps, described as graphical representations of metacognition, was to see how students had synthesized their understandings of the nature of science with the Seabird Project. The maps were determined to be 'good', 'average or medium', or 'poor' based on Lederman et al.'s (2002) eight aspects of the nature of science, as well as other features of scientific work.

Section 4.8 provided details of my methods of data analysis. This section was divided into six subsections and generally followed the sequence described in the previous paragraphs. Lastly, Section 4.9 described the limitations of my methodology. The following two chapters describe my results from the use of quantitative and qualitative methods.

Chapter 5

QUANTITATIVE RESULTS

5.1 Introduction and Overview

As previously discussed in Chapter 3—Research Methods, four instruments were used to produce the survey given to 525 female prospective elementary teachers at California State University, Long Beach, over four semesters of 2002 and 2003. The survey was assembled with the unique instructional format and course goals of *A Process Approach to Science*—SCED 401 in mind. Scales were used from *What Is Happening In this Class?* (Student Cohesiveness, Instructor Support, Investigation, and Cooperation), two from *Science Laboratory Environment Inventory* (Open-Endedness and Material Environment), and one from *Test of Science-Related Attitudes* (Enjoyment of Science Lessons). The *Nature of Scientific Knowledge Survey* (NSKS) was also used. In addition, interviews were conducted with 35 students in the intervention classes (6 out of 27 classes or 22%), an online, open-ended questionnaire about the nature of science was completed by the majority of students, and a small sample of concept maps were collected and analyzed from the intervention classes. This chapter reports my quantitative findings derived from the survey, while Chapter 6 reports the qualitative data and analyses.

This chapter describes the quantitative findings in seven sections. In Section 4.2, the results of a principal components factor analysis for the learning environment portion of the survey are provided. Section 4.3 reports on the internal consistency reliability, discriminant validity, and ability to differentiate between classrooms for the learning environment scales, and also indicates the alpha reliability for the attitude scale. The second portion of the survey, assessing understandings of the nature of science, needed a separate factor analysis—an analytic process that was not conducted on the NSKS when it was first developed in 1978. Results of the factor analysis can be seen in Section 5.4. Internal consistency reliability and discriminant validity, for the *Nature of Scientific Knowledge Survey,* are reported in Section 4.5.

Results of the paired-samples *t*-tests exploring differences between previous laboratory courses (usually one of the prerequisite courses—Physical Science, Biology, or Geology) and SCED 401 scores are provided in Section 5.6 for the learning environment and attitude scales. Differences are reported between students' understandings of the nature of scientific knowledge before SCED 401 began (pretest), and their understandings of the nature of scientific knowledge after SCED 401 (posttest). Differences between the intervention classes, that used the Antarctic seabird database, and those classes that did not—the nonintervention classes—were analyzed as well and reported in Section 5.7.

Lastly, associations between the learning environment and the outcomes of attitude and understandings of the nature of science are outlined in Section 4.8. The last subsection, Section 4.9, provides a summary of the quantitative results chapter by reviewing the specific research questions that were answered through quantitative methods, either in whole or in part.

5.2 Factor Analysis of the Modified Science Learning Environment Survey

The science learning environment survey, specifically developed for the prospective elementary teachers taking SCED 401 at California State University, Long Beach, included scales from the *What Is Happening In this Class?* and the *Science Laboratory Environment Inventory*, making a total of 46 items. Although both instruments have been used extensively in the past, and in many countries, subject areas, and grade levels, and in universities, their use with prospective and preservice teachers has been limited. Because neither instrument was used in its entirety as the original authors had developed them, I needed to investigate whether using only four out of the seven original WIHIC scales, and two out of the six SLEI scales, would still produce a valid and reliable instrument for the prospective elementary teachers. Thus it was necessary to conduct a factor analysis of the modified survey used in my study, and answer the first part of my first research question: *Is it possible to develop valid and reliable measures of prospective elementary teachers' perceptions of the learning environment?*

Table 5.1 indicates the results of the factor analyses for the modified science learning environment survey. A factor analysis was conducted for both the previous laboratory class

Table 5.1

Factor Loadings for Learning Environment Scales Using the Individual as the Unit of Analysis for Previous Laboratory Course and SCED 401

Item No.	Factor Loadings											
	Student Cohesiveness		Instructor Support		Investigation		Cooperation		Open-Endedness		Material Environment	
	Previous Lab Course	SCED 401	Previous Lab Course	SCED 401	Previous Lab Course	SCED 401	Previous Lab Course	SCED 401	Previous Lab Course	SCED 401	Previous Lab Course	SCED 401
1	0.70	0.70										
2	0.52	0.44										
3	0.62	0.71										
4	0.74	0.72										
5	0.66	0.68										
6	0.52	0.53										
7	0.73	0.76										
8	0.46	0.49										
9			0.77	0.75								
10			0.81	0.86								
11			0.82	0.82								
12			0.77	0.81								
13			0.83	0.81								
14			0.80	0.80								
15			0.71	0.69								
16			0.73	0.69								
17					0.72	0.72						
18					0.66	0.64						
19					0.73	0.80						
20					0.65	0.67						
21					0.70	0.73						
22					–	0.71						
23					0.76	0.79						
24					0.74	0.74						
25							0.70	0.61				
26							0.60	–				
27							0.70	0.59				

28							0.74	0.57				
29							0.70	0.75				
30							0.80	0.75				
31							0.78	0.71				
32							0.74	0.76				
33									0.54	0.49		
34									0.63	0.58		
35									–	0.62		
36									0.67	0.68		
37									0.66	0.71		
39									0.56	0.42		
40											0.60	0.67
42											0.63	0.67
43											0.67	0.54
45											0.51	–
46											0.67	0.56
% Var.	4.26	4.22	24.15	25.29	5.73	8.80	10.79	6.60	3.45	3.27	3.17	2.74
Eigen value	1.96	1.94	11.11	11.63	2.64	4.05	4.96	3.04	1.59	1.51	1.46	1.26

Factor loadings smaller than 0.40 have been omitted.

The sample consisted of 525 female prospective elementary teachers in 27 classes in Southern California.

and for SCED 401. Principal components factor analyses with varimax rotation confirmed that the majority of items belonged to one of the six scales with eigen values above unity. In other words, each scale of the modified questionnaire does indeed assess a unique aspect of the science learning environment. The varimax rotation revealed that 41 out of the 46 items assessing previous laboratory courses had loadings above 0.40 on their *a priori* scales and less than 0.40 on the remaining five items. The five items that had factor loadings less than 0.40 included #22 in the Investigation scale, #35 and #38 in Open-Endedness, and #41 and #44 in Material Environment. During the assessment of perceptions of SCED 401, again 41 out of the 46 items had factor loadings above 0.40, although the items whose factor loadings were less than 0.40 were slightly different from previous laboratory classes, namely, #26 in Cooperation, #38 in Open-Endedness, and #41, #44, and #45 in Material Environment. The percentage of variance for previous laboratory classes ranged from 3.17% to 24.15% with a total variance of 51.55%. For SCED 401, the percentage of variance ranged from 2.74% to 25.29% with a total variance of 50.92%. Eigenvalues range from 1.46 to 11.11 and from 1.26 to 11.63 for previous laboratory classes and SCED 401, respectively. Appendix A includes a copy of the modified learning environment survey.

The results of my factor analysis are comparable to other studies that also explored the structure of the WIHIC. For example, the large cross-national study that utilized the WIHIC with 2,960 high school science students in Australia and Taiwan (Aldridge et al., 1999) found average factor loadings for Student Cohesiveness, Teacher (Instructor) Support, Investigation, and Cooperation were 0.60, 0.63, 0.64, and 0.55, respectively. In my study, the average factor loadings were somewhat higher at 0.63, 0.78, 0.72, and 0.68 for the SCED 401 results, using the individual as the unit of analysis. A more recent cross-national study conducted by Dorman (2003) used 3,980 students drawn from Australian, Canadian, and British mathematics high schools, and used confirmatory factor analysis on the WIHIC. Dorman used six items per scale rather than the original eight, and reported high average factor loadings for Student Cohesivesness, Teacher Support, Investigation, and Cooperation, of 0.91, 0.84, 0.88, and 0.81, respectively. Only one study has been conducted with university students using the WIHIC (Margianti, 2002; Margianti et al., 2002). In this study, the sample consisted of 2,498 mathematics university students in 50 classes in Indonesia. On the actual form of the WIHIC, average factor loadings were 0.57, 0.56 and 0.62 for Student Cohesiveness, Instructor Support and Cooperation (Investigation was not used). Percentage variance for these three scales were 2.1%, 2.7%, and 5.3%, in contrast to my values of 4.22%, 25.29% and 6.60% for SCED 401. The high percentage of variance for Instructor Support in my study is probably due to the greater number of instructors who teach the course leading, therefore, to a higher percentage of variance. Percentage variance for Instructor Support in most other studies were more aligned with the Indonesian study than with my study (Aldridge & Fraser, 2000; Aldridge, Fraser, Fisher, Trinidad, & Wood, 2003; Pickett & Fraser, 2004; Soto-Rodriquez & Fraser, 2004), although Raaflaub and Fraser (2003) reported a percentage variance of 21.95% for students' actual perceptions of their laptop computer-enhanced science and mathematics classrooms in Canada.

University students were also involved in the initial development and validation of the *Science Laboratory Environment Inventory.* Fraser et al. (1992a, 1992b, 1993, 1995) used 1,720 university science students in six countries for their study. It is worthwhile to compare their factor analysis results with mine as I also used university students (specifically, prospective elementary teachers). The authors reported average factor loadings for the scales of Open-Endedness and Material Environment of 0.62 and 0.49, for the actual form, using the individual as the unit of analysis. My study had comparable average factor loadings for these two scales of 0.58 and 0.61 for SCED 401. Percentage of variance in the cross-national study for Open-Endedness and Material Environment were 6.4% and 4.7%, respectively, in contrast to 3.27% and 2.74% for SCED 401 in my study.

5.3 Internal Consistency Reliability, Discriminant Validity, and Ability to Differentiate Between Classrooms For Two Units of Analysis for Learning Environment and Attitude Scales

After the factor analyses were conducted for the science learning environment scales, I decided that items having factor loadings greater than 0.40 in either the previous laboratory course or SCED 401, would be used to determine the internal consistency reliability, discriminant validity, and ability to differentiate between classrooms (ANOVA results). By removing these weak items, the internal reliability, factorial validity, and ANOVA results were improved. Consequently, 43 out of 46 items were used producing a common set of items for each scale in order to compare previous laboratory courses and SCED 401 results. The three items omitted are listed below.

#38—Open-Endedness: *"The instructor decided the best way for me to carry out the laboratory experiments."*

#41—Material Environment: *"The equipment and materials that I need for laboratory activities were readily available."*

#44—Material Environment: *"I found that the laboratory was just the right temperature to work in."*

The internal consistency reliability indicates whether each item in a scale assesses a similar construct. Table 5.2 reports that the Cronbach alpha reliability coefficient (Cronbach, 1950) was high for all scales of the learning environment questionnaire for both the previous laboratory course and SCED 401, and for two units of analysis (values over 0.70 are desirable). Cronbach alphas ranged from 0.75 (Material Environment) to 0.94 (Instructor Support) for the previous laboratory course, and from 0.67 (Cooperation) to 0.95 (Instructor Support) for SCED 401, using the individual as the unit of analysis. Using the class mean as the unit of analysis, Cronbach alpha coefficients ranged from 0.71 for Material Environment to 0.95 for Instructor Support for the previous laboratory course, and 0.69 for Material Environment to 0.98 for Instructor Support for SCED 401.

The reliability results mentioned in the previous paragraph compare favorably with other studies that utilized the WIHIC and SLEI. Internal consistency reliability data reported for the WIHIC in Aldridge et al.'s (1999) cross-national study in Taiwan and Australia that utilized 2,960 high school science students were 0.81/0.86 (Australia/Taiwan) for Student Cohesiveness, 0.88/0.87 for Teacher Support, 0.88/0.90 for Investigation, and 0.89/0.87 for Cooperation, using the individual as the unit of analysis. Using the class mean as the unit of analysis, they found Cronbach alphas were higher for the Australia/Taiwan classes on the four scales: 0.87/0.91, 0.95/0.95, 0.95/0.96, and 0.93/0.92, respectively. Dorman's (2003) study in Australia, Canada, and Britain, with high school mathematics students, reported alpha reliabilities of 0.83, 0.84. 0.85, and 0.76 for Student Cohesiveness, Teacher Support, Investigation, and Cooperation, using the individual as the unit of analysis. For his 82 within-school grade groups, alphas were higher at 0.93, 0.94, 0.90 and 0.86 for the four scales. Margianti's (2002) and Margianti et al.'s (2002) study with Indonesian university mathematics students, reported alphas of 0.74, 0.77 and 0.85 for Student Cohesiveness,

Table 5.2

Internal Consistency Reliability (Cronbach Alpha Coefficient) for Learning Environment and Attitude Scales for Two Units of Analysis, Discriminant Validity (Mean Correlation With Other Scales) for Learning Environment Scales for Two Units of Analysis, and Ability to Differentiate Between Classrooms (ANOVA Results) for the Learning Environment

			Alpha Reliability		Mean Correlation with other Scales		ANOVA Eta^2	
Scale	No. of Items	Unit of Analysis	Previous Lab Course	SCED 401	Previous Lab Course	SCED 401	Previous Lab Course	SCED 401
Learning Environment								
Student Cohesiveness	8	Individual	0.86	0.85	0.30	0.30	0.07	0.14**
		Class Mean	0.88	0.92	0.54	0.42		
Instructor Support	8	Individual	0.94	0.95	0.32	0.34	0.04	0.23**
		Class Mean	0.95	0.98	0.46	0.37		
Investigation	8	Individual	0.89	0.92	0.36	0.34	0.10**	0.12**
		Class Mean	0.91	0.96	0.50	0.36		
Cooperation	8	Individual	0.92	0.67	0.26	0.34	0.06	0.11**
		Class Mean	0.93	0.82	0.40	0.40		
Open-Endedness	6	Individual	0.80	0.80	0.27	0.28	0.07*	0.09*
		Class Mean	0.85	0.87	0.48	0.46		
Material Environment	5	Individual	0.75	0.69	0.15	0.17	0.04	0.08*
		Class Mean	0.71	0.69	0.17	0.22		
Attitude								
Enjoyment of Science Lessons	8	Individual	0.95	0.93				
		Class Mean	0.96	0.98				

*$p<0.05$ ** $p<0.01$

The sample consisted of 525 female prospective elementary teachers in 27 classes in Southern California.

The eta^2 statistic (which is the ratio of 'between' to 'total' sums of squares) represents the proportion of variance explained by class membership.

Instructor Support, and Cooperation (Investigation was not used), using the individual as the unit of analysis. Using the class mean as the unit of analysis, Margianti and colleagues reported alphas of 0.68, 0.92 and 0.84 for the three scales. Alpha reliabilities for SLEI scales, as reported in Fraser et al.'s (1992a, 1993, 1995) cross-national study involving university science students, were 0.65 for Open-Endedness and 0.72 for Material Environment, using the individual as the unit of analysis on the actual form. Using the class mean as the unit of analysis, alpha coefficients were 0.76 for Open-Endedness and 0.79 for Material Environment.

In order to answer the second part of my first research question: *Is it possible to develop valid and reliable measures of prospective elementary teachers' attitudes towards science,* the internal consistency reliability for the attitude scale called Enjoyment of Science Lessons, which was extracted from the TOSRA (Fraser, 1981), was also calculated. The resulting Cronbach alpha was very strong. The Cronbach alpha coefficient was 0.95 for previous laboratory courses and 0.93 for SCED 401 (using the individual as unit of analysis), and 0.96 for previous laboratory courses and 0.98 for SCED 401 (using class mean as the unit of analysis). These results, again, replicate past studies that utilized scales from the TOSRA (Adolphe et al., 2003; Fraser & Butts, 1982; Fraser & Fisher, 1982; Goh et al., 1995; Wong & Fraser, 1994, 1996; Wong et al., 1997).

Discriminant validity indicates whether each learning environment scale assesses a separate construct. The mean correlation of a scale with other scales was used as a convenient index of discriminant validity. Table 5.2 indicates that the discriminant validity of the learning environment scales is acceptable but the scales do overlap somewhat, although not to the extent that would violate the psychometric structure of the instrument. Mean correlation values range from 0.15 for Material Environment to 0.36 for Investigation for previous laboratory courses, using the individual as the unit of analysis. Values ranged from 0.17 for Material Environment to 0.34 for Instructor Support, Investigation, and Cooperation for SCED 401. Using the class mean as the unit of analysis, the discriminant validity values were consistently higher for both previous laboratory courses and SCED 401 compared to the values using the individual as the unit of analysis. For previous laboratory courses, values of the mean correlation ranged from 0.17 for Material Environment to 0.54 for Student Cohesiveness. For SCED 401, values ranged from 0.22 for Material Environment to 0.46 for Open-Endedness with the class mean level.

The discriminant validity values mentioned in the above paragraph are comparable to other studies. Dorman (2003), for example, reported mean correlations with other scales of 0.32, 0.42, 0.40 and 0.42 for Student Cohesiveness, Teacher Support, Investigation, and Cooperation, using the individual as the unit of analysis. Using within-school grade means, Dorman reported values of 0.34, 0.38, 0.27 and 0.46 for the four WIHIC scales. Margianti (2002) reported mean correlations with other scales of 0.37, 0.37 and 0.35 for Student Cohesiveness, Instructor Support and Cooperation, using the individual as the unit of analysis. Using class means, Margianti found mean correlations were considerably higher for the three WIHIC scales that she used: 0.55, 0.67 and 0.82. Fraser et al.'s (1992a) study reported mean correlations with other scales of 0.12 and 0.28 for Open-Endedness and Material Environment on the SLEI, using the individual as the unit of analysis. Using the class mean as the unit of analysis, correlations were 0.19 and 0.28 for the two scales.

To further check the validity of the learning environment scales, a one-way ANOVA was used to indicate whether each scale differentiated significantly between perceptions of prospective elementary teachers in different university classes. Theoretically, students within the same class should perceive the class similarly, while mean within-class perceptions should vary from class to class. The eta^2 statistic is the ratio of the 'between' to 'total' sums of the squares, and is an estimate of the strength of the association between class membership and the dependent variable, namely, a learning environment scale. It should be noted, however, that the eta^2 statistic for the previous laboratory course in Table 5.2 represents a high degree of variability. This is because a variety of different laboratory courses could have been taken by the prospective elementary teachers prior to beginning SCED 401. As mentioned earlier, the previous laboratory course was likely to be one of the prerequisite science courses (Biology, Physical Science, or Geology), but students also had a variety of instructors and many students took their prerequisite courses at a junior college before transferring to California State University, Long Beach. Nevertheless, values for each learning environment scale's ability to differentiate between classrooms were satisfactory, as can be seen in Table 5.2. For previous laboratory courses, only Investigation ($\text{eta}^2=0.10$, $p<0.01$) and Open-Endedness ($\text{eta}^2=0.07$, $p<0.05$) were statistically significant. For SCED 401, however, all six learning environment scales differentiated significantly between classrooms ($p<0.05$). The eta^2 statistic ranged from 0.08 for Material Environment to 0.23 for Instructor Support for SCED 401.

The SCED 401 ANOVA results are comparable to other studies using the WIHIC and SLEI. Fraser et al.'s (1992a) study reported eta^2 statistics of 0.20 ($p<0.001$) for Open-Endedness, and 0.24 ($p<0.001$) for Material Environment. Dorman (2003) reported eta^2 statistics of 0.09, 0.12, 0.08 and 0.08 for Student Cohesiveness, Teacher Support, Investigation, and Cooperation.

5.4 Factor Analysis for the Nature of Scientific Knowledge Survey—NSKS

After a factor analysis was conducted on the learning environment scales derived from the WIHIC and the SLEI, a second factor analysis was needed for the *Nature of Scientific Knowledge Survey* (NSKS), and its six scales. This was necessary in order to answer the third part of my research question: *Is it possible to develop valid and reliable measures of prospective elementary teachers' understandings of the nature of science?*

Table 5.3 indicates that the principal components factor analysis for the NSKS was not as strong as for the learning environment portion of the survey. Therefore, rather than using a factor loading of 0.40 as the cut-off point, as was done for the learning environment scales, factor loadings of less than 0.30 were omitted in Table 5.3. Only four of the six scales had a sufficient number of items with values over 0.30—Creative, Testable, Unified, and Amoral. The scales of Parsimonious and Developmental were omitted due to their weak structure. For understandings based on students' overall science education experience before SCED 401 (i.e., the pretest), one item from the Creative scale (#44), one from the Unified scale (#24), and two items from the Testable (#17 and #47) scale had factor loadings less than 0.30. Three items from the Amoral scale, namely, #1, #19, and #37, had loadings less than 0.30. Appendix A indicates these items in a copy of the *Nature of Scientific Knowledge Survey.*

The percentage of variance for the pretest varies from 2.43% to 12%, with a total variance of 24.63% for the four scales. Eigenvalues ranged from 1.17 to 5.75.

For understandings of the nature of science after SCED 401 (i.e., the posttest), the same seven items on the Creative scale had factor loadings greater than 0.30. For the Unified scale, two of the eight items had factor loadings less than 0.30 (#30 this time in addition to #24). Both the Testable and Amoral scales had more items with factor loadings greater than

0.30 after SCED 401 compared to the pretest scores. Item #47 from the Testable scale and Items #1 and #37 from the Amoral scale had factor loadings less than 0.30.

Table 5.3
Factor Loadings for the Nature of Scientific Knowledge Survey (NSKS) Scales Using the Individual as the Unit of Analysis For Before and After SCED 401

	Factor Loadings							
	Creative		Testable		Unified		Amoral	
Item No.	Before SCED 401 (pretest)	After SCED 401 (posttest)	Before SCED 401 (pretest)	After SCED 401 (posttest)	Before SCED 401 (pretest)	After SCED 401 (posttest)	Before SCED 401 (pretest)	After SCED 401 (posttest)
2	0.56	0.62						
8	0.70	0.73						
14	0.81	0.71						
20	0.47	0.56						
26	0.78	0.74						
32	0.57	0.59						
38	0.70	0.72						
5			0.32	0.34				
11			0.32	0.36				
17			–	0.35				
23			0.58	0.55				
29			0.34	0.65				
35			0.31	0.51				
41			0.57	0.59				
6					0.72	0.74		
12					0.80	0.73		
18					0.80	0.70		
30					0.37	–		
36					0.50	0.40		
42					0.35	0.34		
48					0.54	0.51		
7							0.57	0.53
13							0.58	0.40
19							–	0.44
25							0.33	0.31
31							0.36	0.30
43							0.51	0.65
							0.57	0.53
% Var.	12.00	14.31	6.65	5.47	3.55	3.58	2.43	2.53
Eigen value	5.75	6.87	3.19	2.63	1.70	1.72	1.17	1.21

Factor loadings smaller than 0.30 have been omitted.
The sample consisted of 525 female prospective elementary teachers in 27 classes in Southern California.

Percentage of variance for the posttest varies from 2.53% to 14.31%, with a total variance of 25.89%. Eigenvalues ranged from 1.21 to 6.87.

The results of my factor analysis for the NSKS are comparable to Bright and Yore's (2002) study in British Columbia, Canada. They examined 50 preservice elementary teachers' beliefs about the nature of science over the duration of a year-long science methods course and embedded teaching practicum. Their principal components factor analysis on the pretest of the NSKS, yielded average factor loadings of 0.67 for Creative, 0.58 for Testable, and 0.54 for Amoral. They found that the scales of Parsimonious, Development, and Unified had many items with factor loadings less than 0.30. For my pretest, the comparable average factor loadings had the lower values for the Creative, Testable and Amoral scales of 0.66, 0.41 and 0.47. Bright and Yore reported the percentage of variance for the scales of Creative, Testable and Amoral as 9.93%, 8.45%, and 9.41%, respectively, for the pretest. In my study, the comparable values were 2.43%, 12%, and 6.65%. For the posttest, Bright and Yore found that average factor loadings were higher, namely, 0.61 for Creative, 0.58 for Testable, 0.63 for Unified, 0.63 for Amoral, and 0.50 for Parsimonious. Bright and Yore found that only the scale of Development exhibited weak factorial structure, with many items with loadings less than 0.30 on the posttest. For my posttest (i.e., after SCED 401), the comparable average factor loadings for Creative, Testable, Unified and Amoral were 0.67, 0.48, 0.57 and 0.44, which are higher than the pretest as Bright and Yore also found, but not as high as their posttest factor loadings. Bright and Yore reported percentage variances for the posttest of 9.54%, 10.35%, and 7.37%, respectively, for Creative, Testable, and Amoral. My percentage variances were 14.31%, 5.47%, and 2.53% for these three scales.

5.5 Internal Consistency Reliability and Discriminant Validity for Nature of Scientific Knowledge Survey

Based on the same criteria used for the science learning environment scales, it was decided that items with factor loadings greater than 0.30 on *either* the pretest *or* the posttest would be used to calculate the internal consistency and discriminant validity of the NSKS scales. Again, this would give a common set of items from each scale for these additional analyses. Development and Parsimonious scales were not used because the Development scale had several items that overlapped with the Testable scale, while the Parsimonious scale only had three items on the pretest and one item on the posttest with factor loadings greater than 0.30. As a result, 27 of the 48 items on the NSKS had factor loadings greater than 0.30 on either the pretest or posttest, and were retained for reliability and validity analyses.

Table 5.4 indicates that the Cronbach alpha coefficients for the four scales assessing understandings before SCED 401 (pretest) were fairly high. Values for the individual as the unit of analysis ranged from 0.57 for Amoral to 0.84 for Creative. After SCED 401 (posttest), values ranged from 0.66 for Amoral to 0.85 for Creative. Similar to the learning environment and attitude scales, alpha reliability values using the class mean as the unit of analysis were higher. Before SCED 401, values ranged from 0.74 for Amoral to 0.87 for Creative. After SCED 401, values ranged from 0.59 for Testable to 0.91 for Creative. These results indicate that, by removing 21 of the 48 items, the internal consistency reliability of the remaining four scales improved considerably.

Table 5.4

Internal Consistency Reliability (Cronbach Alpha Coefficient) and Discriminant Validity (Mean Correlation With Other Scales) for Two Units of Analysis for the Nature of Scientific Knowledge Survey (NSKS) Scales

			Alpha Reliability		Mean Correlation with other Scales	
Scale	No. of Items	Unit of Analysis	Before SCED 401 (pretest)	After SCED 401 (posttest)	Before SCED 401 (pretest)	After SCED 401 (posttest)
Creative	7	Individual	0.84	0.85	0.15	0.20
		Class Mean	0.87	0.91	0.19	0.05
Testable	7	Individual	0.72	0.71	0.21	0.28
		Class Mean	0.77	0.59	0.29	0.15
Unified	7	Individual	0.79	0.75	0.23	0.27
		Class Mean	0.79	0.60	0.30	0.13
Amoral	6	Individual	0.57	0.66	0.12	0.11
		Class Mean	0.74	0.76	0.30	0.08

The sample consisted of 525 female prospective elementary teachers in 27 classes in Southern California.

It is interesting to compare the Cronbach alpha coefficient for the NSKS scales for my sample with Bright and Yore's (2002) study. For the pretest, they reported alpha coefficients of 0.83, 0.69, 0.73 and 0.75 for the scales of Creative, Testable, Unified and Amoral, which are slightly lower than values in my study, with the exception of the Amoral scale which had an alpha considerably higher. For their posttest, alpha coefficients were 0.74, 0.73, 0.78 and 0.78 for Creative, Testable, Unified and Amoral (compared to 0.85, 0.71, 0.75 and 0.66 for my study, respectively, for the four scales).

Table 5.4 also indicates that the discriminant validity of the four NSKS scales was fairly good. As mentioned earlier, this is probably due to the elimination of 21 items, including all items in the scales of Parsimonious and Development. Table 5.4 shows that, for the pretest, discriminant validity ranged from 0.12 for Amoral to 0.23 for Unified, using the individual as the unit of analysis. On the posttest, values ranged from 0.11 for Amoral to 0.28 for Testable. Using the class mean as the unit of analysis, values ranged from 0.19 for Creative to 0.30 for Unified and Amoral, on the pretest. For the posttest, values ranged from 0.05 for Creative to 0.15 for Testable. Overall, this suggests quite good discriminant validity for the NSKS. Unfortunately, comparisons with the Bright and Yore (2002) study cannot be made as they did not calculate the discriminant validity.

5.6 Differences Between Previous Laboratory Courses and SCED 401 in Learning Environment and Attitude, and Differences Between Before and After SCED 401 for Nature of Scientific Knowledge Survey

This section describes how I answered my third research question: *Are there differences between students' previous laboratory course and A Process Approach to Science (SCED 401) in terms of:*

(a) perceptions of the learning environment,
(b) attitudes towards science, and
(c) understandings of the nature of science?

A student's previous laboratory course was usually one of the prerequisite courses (Biology 200, Physical Science 112, or Geology 104) taken at either California State University, Long Beach or a community junior college. Students' perceptions of the learning environment and attitudes towards science were assessed based on one of these courses. Understanding the nature of science, however, was based on students' overall science education experience (i.e., the pretest) prior to SCED 401 (not just one course). Comparisons were then made with their understanding after SCED 401 (i.e., the posttest).

Descriptive statistics comparing the students' perceptions of the learning environment and attitudes towards science during their previous laboratory course and SCED 401, using the class mean as the unit of analysis, are provided in Table 5.5. Descriptive statistics describing understandings of scientific knowledge before and after SCED 401 are also provided in Table 5.5. Figure 5.1 graphically compares the average item mean (scale mean divided by the number of items in that scale) for previous laboratory courses and SCED 401 for the learning environment and attitude scales, while Figure 5.2 compares the Nature of Scientific Knowledge Survey scores before and after SCED 401. The average item mean was used because this allowed meaningful comparisons to be made between scales with differing numbers of items (WIHIC scales had 8 items, and the SLEI scales had 7 items).

For the learning environment/attitude scales, scores greater than '3' indicate that prospective elementary teachers perceived practices related to each psychosocial variable as occurring more frequently than *sometimes* and in the direction of *often* or *almost always*. Scores of less than 3 indicate that these practices are perceived as happening less frequently than *sometimes* and in the direction of *seldom* or *almost never*. For the NSKS scales, mean scores greater than 3 indicate that prospective elementary teachers are moving in the direction of *agreeing* or *strongly agreeing* with the statement about the nature of scientific knowledge. Teachers assessed their own understanding based on the knowledge, skills, and experiences gained throughout their entire science education experience *before* SCED 401 (pretest), and then after SCED 401 (posttest). Scores of less than 3 indicate that prospective elementary teachers tend to *disagree* or *strongly disagree* with the statement.

Table 5.5 shows that the average item mean for all seven scales on the learning environment and attitude portion of the survey increased for SCED 401, ranging from a mean difference of 0.31 for Student Cohesiveness to 1.55 for Open-Endedness. Four of the scales showed an average item mean difference close to or over 1.00—Instructor Support (0.94), Investigation (0.98), Open-Endedness (1.55), and Enjoyment of Science Lessons (0.97). Understandings of the nature of scientific knowledge, as measured by the NSKS scales of Creative, Testable, Unified, and Amoral, all improved after SCED 401 as well. The greatest change occurred with the Creative scale that had an average item mean difference of 0.41. In summary, the

Table 5.5

Average Item Mean, Average Item Standard Deviation, and Differences (Effect Size and t-test for Paired Samples) For Previous Laboratory Course and SCED 401 for Learning Environment and Attitude Scales, and Before and After SCED 401 for Nature of Scientific Knowledge Survey (NSKS) Scales Using the Class Mean as the Unit of Analysis

	Average Item Mean		Average Item Standard Deviation		Difference	
Scale	Previous Lab Course	SCED 401	Previous Lab Course	SCED 401	Effect Size	*t*
Learning Environment						
Student Cohesiveness	4.13	4.44	0.20	0.21	1.51	7.32**
Instructor Support	3.26	4.20	0.23	0.40	2.98	12.91**
Investigation	3.43	4.41	0.30	0.22	3.77	15.97**
Cooperation	4.39	4.72	0.17	0.16	2.00	7.78**
Open-Endedness	2.30	3.85	0.24	0.22	6.74	34.54**
Material Environment	3.77	4.40	0.16	0.17	3.82	15.20**
Attitude						
Enjoyment of Science Lessons	3.09	4.06	0.27	0.38	2.98	15.06**
	Before SCED 401 (pretest)	After SCED 401 (posttest)	Before SCED 401 (pretest)	After SCED 401 (posttest)	Effect Size	*t*
NSKS						
Creative	3.42	3.83	0.18	0.22	2.05	9.62**
Testable	4.00	4.05	0.14	0.12	0.38	1.89
Unified	3.82	4.02	0.12	0.12	1.67	7.93**
Amoral	3.28	3.30	0.16	0.17	0.12	0.39

**$p<0.01$ (Using modified Bonferroni procedure with 11 tests)

For the Learning Environment and Attitude scales, the response key was: 1=Almost Never, 2=Seldom, 3=Sometimes, 4=Often, 5=Almost Always.

For the NSKS, the response key was: 1= Strongly Disagree, 2=Disagree, 3= Neutral, 4=Agree, 5=Strongly Agree

N=525 female prospective elementary teachers in 27 classes in Southern California.

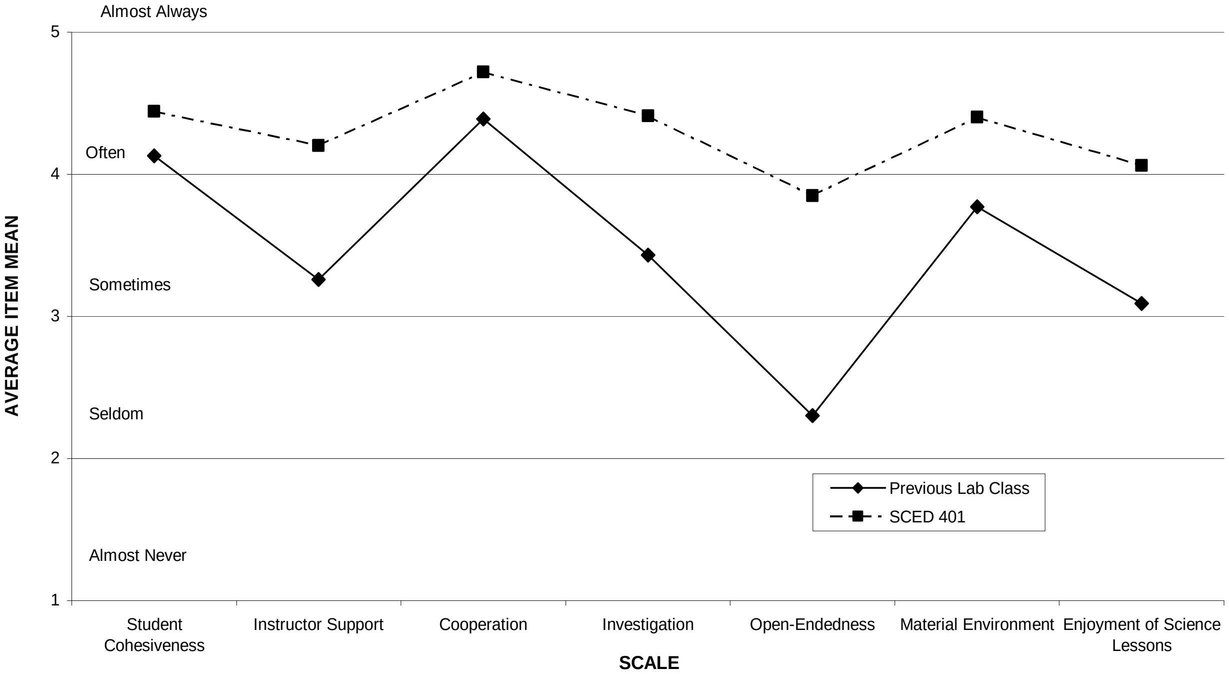

Figure 5.1. Average item mean for previous laboratory class and SCED 401 for learning environment and attitude scales using the class mean as the unit of analysis (*N* =27)

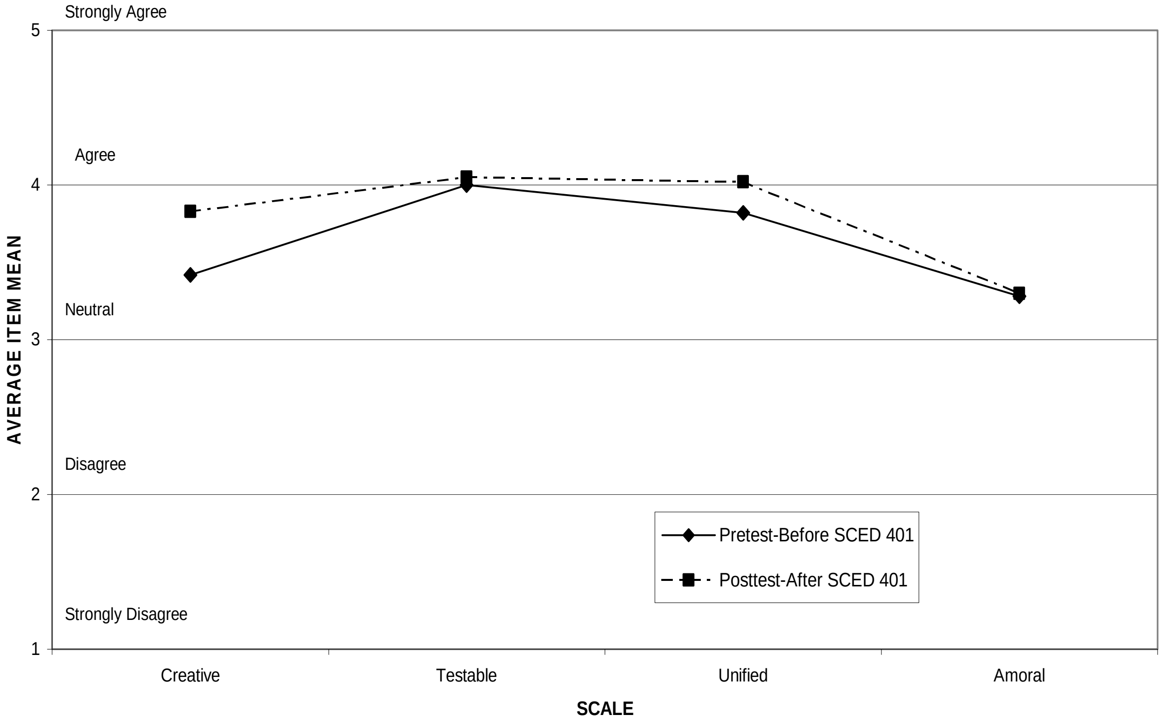

Figure 5.2. Average item mean before SCED 401 and after SCED 401 for scales on the Nature of Scientific Knowledge Survey using the class mean as the unit of analysis (*N* =27)

results reveal that prospective elementary teachers generally rated their previous laboratory courses as having a positive learning environment, with the exception of Open-Endedness that received a mean score of 2.30 (i.e., these courses *seldom* had divergent experiments or investigations, or *seldom* allowed students to pursue their own science interests). Despite these relatively positive results for previous laboratory courses, dramatic gains were still made for all learning environment scales assessing SCED 401. The same pattern was observed with attitudes towards science as measured by the Enjoyment of Science Lessons scale.

Based on prospective elementary teachers' overall science education experience prior to beginning SCED 401, understandings of scientific knowledge were assessed as fairly good on the four scales. Again, however, improvements were made on all NSKS scales after prospective elementary teachers had completed SCED 401.

Effect sizes (Thompson, 1998) reveal the magnitude of differences between previous laboratory courses and SCED 401 for each scale. This was calculated by dividing the difference between the previous laboratory course and SCED 401 means by the pooled standard deviation. Effect sizes are generally not expected to be large in the behavioral sciences (Cohen, 1988, p. 284). Cohen states that effect sizes of 0.10 and less are considered small, 0.25 reveals a moderate effect size, and 0.40 and above indicates a large effect size.

Table 5.5 indicates that the effect size was unusual for all learning environment scales with values ranging from 1.51 standard deviations for Student Cohesiveness to 6.74 standard deviations for Open-Endedness, using the class mean as the unit of analysis. It should be noted, however, that because I am using the class mean as the unit of analysis, standard deviations are small, therefore, resulting in large effect sizes. For the attitude scale from the TOSRA, Enjoyment of Science Lessons, the difference between previous laboratory classes and SCED 401 showed an effect size of 2.98 standard deviations. The effect size for each NSKS scale was calculated by dividing the difference between the mean scores before and after SCED 401 by the pooled standard deviation. The effect size was small for two scales on the NSKS and large for two scales (e.g., 2.05 for Creative).

T-tests for paired samples were calculated for the 11 scales to ascertain the statistical significance of any differences between students' previous laboratory course and SCED 401 in terms of the learning environment and attitudes towards science, and between before and after SCED 401 for understandings of the nature of science. Table 5.5 indicates that the *t*-test results were significant for all scales assessing the learning environment and attitude, and for the scales of Creative and Unified on the NSKS, at a 99 percent confidence level, even with using the modified Bonferroni procedure (Holland & DiPonzio Copenhaver, 1988; Jaccard & Wan, 1996). The Bonferroni procedure is a statistical tool that ensures statistical testing is not compromised by sample size or by the number of tests performed. It safeguards from blindly accepting statistical differences or Type I errors that can result from multiple *t*-tests. Using this procedure, *t* values are first ranked from most significant to least significant (lowest to highest *p* value), and dividing the most significant *p*-value by the total number of tests performed (*n*). In my study, 11 tests were performed. If the resulting *p*-value is less than the desired alpha (i.e., 0.01), the difference is still considered significant. The second difference is considered significant if the resulting *p*-value is less than the desired alpha after dividing by *n*-1. This procedure is continued for each successive *p*-value by dividing by *n–k* until a statistically nonsignificant result is obtained. In my study, the most significant *t* (Open-Endedness) was accepted because its *p*-value was less than 0.01. For the second most significant *t* (Investigation), 0.01 was divided by 10 (i.e., resulting in 0.005, and because its *p*-value was less than this figure, it was still statistically significant. For the third test (Material Environment), 0.01 was divided by nine resulting in 0.0011, and because its *p*-value was less than this figure, it was also still statistically significant. In my study's case, nine out of 11 tests were statistically significant using the modified Bonferroni procedure.

5.7 Differences Between Intervention and Nonintervention Classes for Learning Environment, Attitude and Nature of Scientific Knowledge Survey

The Antarctic Seabird database was used to improve the experimental design project, which typically took place during the last month of the course. In providing actual scientific data on the growth rates of four species of petrels (related to an albatross), I wanted the students to experience *authentic scientific inquiry* (i.e., in the six intervention classes). The wildlife biologist who collected the data over two seasons of field work in Antarctica, also participated in my classes, by visiting students during the project and guiding them along the process. By providing more in-class time to work on the project, as well, Dr Hodum and I felt students would better understand the nature of science, and what actual scientists do. In the 21 nonintervention classes, students collected their own primary data individually, chose their own topic, but did not spend as much in-class time working on their project. Another major difference between the intervention and nonintervention classes was that I had students write their report in groups of two or three people, while the instructors in the nonintervention classes had their students produce reports individually.

My fourth research question involves the intervention and was: *How does using real research data on Antarctic seabirds in the course affect prospective elementary teachers' perceptions of the learning environment, attitudes towards science, and understandings of the nature of science?* Descriptive statistics (i.e., average item means, standard deviations, and differences) were applied to the six intervention classes (22% of total sample) that used the Antarctic seabird database, and the 21 nonintervention classes that did not.

Table 5.6 reports the differences between the six classes that had the Antarctic seabird data integrated into the course—the intervention—versus the 21 classes that did not, using the class mean as the unit of analysis. Figure 5.3 illustrates these differences in a graphical format. For the intervention classes, two learning environment scales, namely, Instructor Support and Material Environment had higher average item means than for the nonintervention classes, but neither were statistically significant. Enjoyment of Science Lessons also had a higher average item mean in the intervention classes, and this was statistically significant ($p<0.05$). One learning environment scale, namely, Cooperation, had the exact same average item mean for both groups. Three scales, namely Student Cohesiveness, Investigation, and Open-Endedness, had lower average item means for the intervention classes compared to the nonintervention classes, with the difference for Student Cohesiveness being statistically significant ($p<0.05$).

For the NSKS, two scales had average item means that were higher for the intervention classes—Creative and Amoral, with Creative being statistically significant ($p<0.05$). Two scales had lower scores for the intervention classes—Testable and Unified, but neither were statistically significant. The NSKS results are represented graphically in Figure 5.4.

In terms of effect sizes for the learning environment and attitude scales for which the intervention classes has higher scores, values were 0.15 standard deviations for Instructor Support, 3.31 standard deviations for Material Environment, and 1.44 for Enjoyment of

Science Lessons when the class mean was used as the unit of analysis (see Table 5.6). The three scales that had lower average item means in the intervention classes revealed effect sizes of 1.53 for Student Cohesiveness, 0.37 for Investigation, and 0.95 for Open-Endedness. For the NSKS, the Creative and Amoral scales for the intervention classes had effect sizes of 1.03 and 0.64 standard deviations, respectively. For the Testable and Unified scales that were lower for the intervention classes, effect sizes were 0.42 and 0.87.

Table 5.6
Average Item Mean, Average Item Standard Deviation, and Differences (Effect Size and t-test for Independent Samples) Between Nonintervention and Intervention Classes for Learning Environment, Attitude and Nature of Scientific Knowledge Scales Using the Class Mean as the Unit of Analysis

	Average Item Mean		Average Item Standard Deviation		Difference	
Scale	Non-Intervention	Intervention	Non-Intervention	Intervention	Effect Size	*t*
Learning Environment						
Student Cohesiveness	4.49	4.26	0.21	0.09	1.53	–2.62*
Instructor Support	4.19	4.24	0.45	0.20	0.15	0.25
Investigation	4.43	4.36	0.24	0.14	0.37	–0.68
Cooperation	4.72	4.72	0.24	0.12	0.00	0.01
Open-Endedness	3.90	3.70	0.21	0.21	0.95	–1.94
Material Environment	4.39	4.45	0.18	0.11	0.41	0.86*
Attitude						
Enjoyment of Science Lessons	3.97	4.38	0.36	0.21	1.44	2.64*
NSKS						
Creative	3.79	3.98	0.22	0.15	1.03	2.06*
Testable	4.06	4.02	0.13	0.06	0.42	–0.77
Unified	4.04	3.94	0.11	0.12	0.87	–1.90
Amoral	3.28	3.37	0.18	0.10	0.64	1.13

*$p<0.05$
For the Learning Environment and Attitude scales, the response key was: 1=Almost Never, 2=Seldom, 3=Sometimes, 4=Often, 5=Almost Always.
For the NSKS, the response key was: 1= Strongly Disagree, 2=Disagree, 3= Neutral, 4=Agree, 5=Strongly Agree.
Nonintervention=21 classes of SCED 401; intervention=6 classes of SCED 401

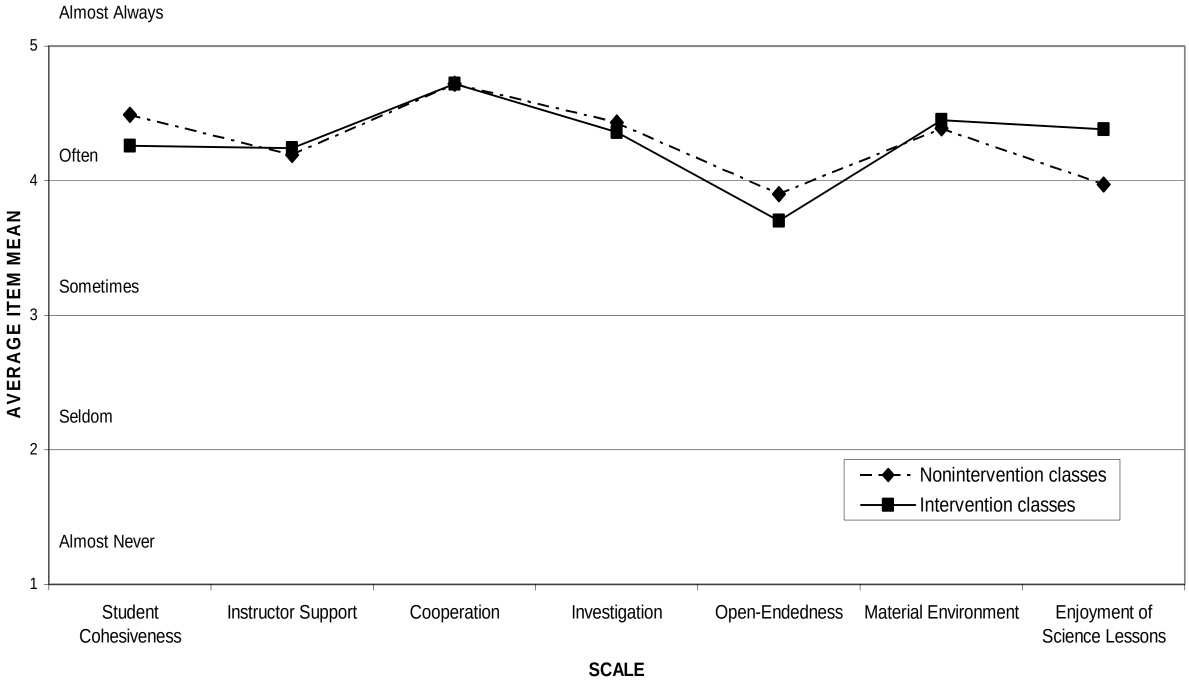

Figure 5.3. Average item mean for nonintervention and intervention classes for learning environment and attitude scales using the class mean as the unit of analysis

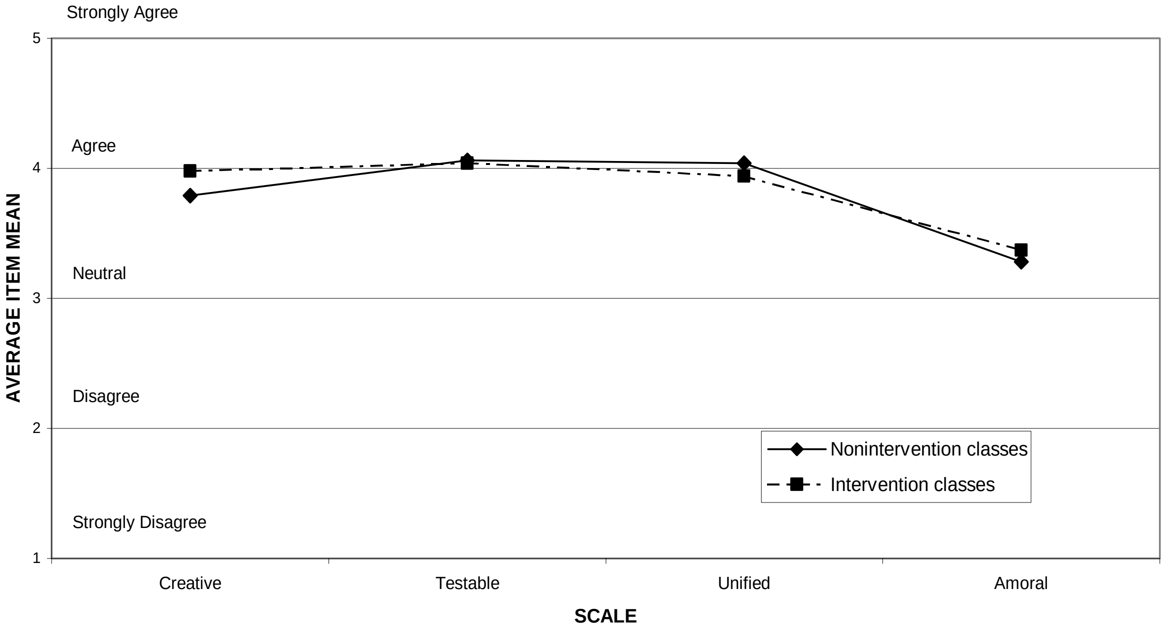

Figure 5.4. Average item mean for nonintervention and intervention classes for scales on the Nature of Scientific Knowledge Survey using the class mean as the unit of analysis

5.8 Associations Between Learning Environment, Attitude and the Nature of Science

My fifth research question was: *Are there associations between learning environment and the student outcomes of attitudes towards science, and understandings of nature of science?* In order to answer this question, simple correlation and multiple regression analyses were carried out, using both the individual and class mean as the units of analysis. Stern et al. (1956) noted that private beta press and consensual beta press can differ from each other. In my study, I used wording in my modified learning environment and attitude questionnaire to reflect a personal view, although I did not investigate any differences between subgroups within classes. All of my research questions reflect a consensual beta press perspective so class mean as the unit of analysis is also appropriate. Overall, "the gains in objectivity and generalizability associated with use of consensual press measures need to be weighed against the potential loss of information about individual students within a class" (Fraser, 1986b, p. 11).

The results of the simple correlation and multiple regression analyses are reported in Table 5.7. Simple correlations (*r*) reveal the bivariate association between the dependent variables of attitude and understandings of the nature of science, and each of the six learning environment scales (but does not hold the other five scales constant). Focusing on attitude first, as assessed by Enjoyment of Science Lessons from the TOSRA, Table 5.7 shows that the simple correlations were statistically significant ($p<0.01$) for all six learning environment scales, using the individual as the unit of analysis. With the class mean as the unit of analysis, only the two learning environment scales of Instructor Support ($r=0.75$; $p<0.01$) and Material Environment ($r=0.44$; $p<0.05$) were significantly correlated with Enjoyment of Science Lessons. For each unit of analysis, the simple correlation between Instructor Support and Enjoyment of Science Lessons was the highest of all six learning environment scales.

Looking at the second dependent variable, understandings of the nature of science as assessed by the four scales on the NSKS, Table 5.7 reveals relatively weak correlations with learning environment. Nevertheless, several were statistically significant, using the individual as the unit of analysis. The simple correlation values ranged from $r=-0.02$ for Amoral to $r=0.22$ ($p<0.01$) for Testable, using the individual as the unit of analysis. Using the class mean as the unit of analysis, values range from $r=-0.02$ for Testable to $r=-0.37$ for Amoral, but all correlations were statistically nonsignificant.

The multiple correlation (R) analysis provides a test of the combined influence of the six independent learning environment variables on attitude and the nature of scientific knowledge. This analysis provides more straightforward information about learning environment-attitude and learning environment-nature of scientific knowledge associations, and reduces the risk of a Type I error often linked with simple correlation analysis. Table 5.7 indicates a statistically significant ($p<0.01$) multiple correlation between the learning environment and attitude (Enjoyment of Science Lessons), for both units of analysis. Because a multiple correlation coefficient of 1.00 indicates perfect correlation, the results of $R=0.66$ for the individual unit of analysis and $R=0.82$ for the class mean can be considered high. Table 5.7 also indicates a statistically significant ($p<0.01$) multiple correlation between the learning environment and the three scales of Creative ($R=0.22$), Testable ($R=0.29$), and Unified ($R=0.27$) on the NSKS, using the individual as the unit of analysis. Using the class mean as the unit of analysis, the multiple correlation between each NSKS scale and the set of learning environment scales was nonsignificant in every case.

To determine which specific learning environment scales account for most of the variance for the Enjoyment of Science Lessons and the Nature of Scientific Knowledge scales, standardized regression weights were examined. The regression coefficient (ß) indicates the strength of the association of each learning environment scale on the Enjoyment of Science Lessons and Nature of Scientific Knowledge scales when the five other learning environment scales are mutually controlled. Table 5.7 indicates that, for the individual unit of analysis, the scale of Instructor Support had the largest independent influence (ß=0.51; $p<0.01$) on Enjoyment of Science Lessons, although Open-Endedness and Material Environment were also significant independent predictors (ß=0.12; $p<0.01$ and ß=0.20; $p<0.01$, respectively). Using the class mean as the unit of analysis, Instructor Support was a statistically significant independent predictor of Enjoyment of Science Lessons (ß=0.87; $p<0.01$).

Because the multiple correlations were statistically significant for the Creative, Testable and Unified scales of the Nature of Scientific Knowledge Survey at the individual level of analysis, I examined the standardized regression coefficients to identify which individual learning environment scales were most influential. Table 5.7 shows that Open-Endedness

Table 5.7

Simple Correlation and Multiple Regression Analyses for Associations Between the Learning Environment, Enjoyment of Science Lessons, and the Nature of Scientific Knowledge using Two Units of Analysis

Scale	Unit of Analysis	Enjoyment of Science Lessons		Creative		Testable		Unified		Amoral	
		r	β	r	β	r	β	r	β	r	β
Student Cohesiveness	Individual	0.17**	–0.06	0.05	–0.00	0.16**	0.03	0.14**	0.07	–0.02	–0.01
	Class	0.04	–0.10	–0.15	–0.35	0.21	0.57	0.29	0.58	–0.37	–0.26
Instructor Support	Individual	0.61**	0.51**	0.11*	0.01	0.16**	0.01	0.12**	–0.02	0.04	0.02
	Class	0.75**	0.87**	0.26	0.27	0.22	0.63	0.12	0.27	–0.13	0.04
Investigation	Individual	0.35**	0.07	0.12**	0.03	0.21**	0.08	0.17**	0.10	0.04	0.04
	Class	0.18	0.08	0.03	–0.05	–0.20	–0.47	0.18	0.27	–0.22	0.05
Cooperation	Individual	0.22**	–0.01	0.06	–0.02	0.22**	0.12*	0.15**	0.03	–0.05	–0.09
	Class	0.32	–0.14	0.05	0.10	0.16	–0.36	0.21	–0.28	–0.22	–0.06
Open-Endedness	Individual	0.36**	0.12**	0.19**	0.16**	0.19**	0.10*	0.13**	0.05	0.06	0.04
	Class	0.28	–0.22	0.06	0.11	–0.02	–0.16	0.03	–0.54	–0.29	–0.25
Material Environment	Individual	0.34**	0.20**	0.13**	0.11*	0.16**	0.10*	0.21**	0.17**	0.05	0.06
	Class	0.44*	0.26	0.10	–0.00	–0.10	–0.34	–0.05	0.02	0.04	0.17
Multiple Correlation (R)	Individual		0.66**		0.22**		0.29**		0.27**		0.11
	Class		0.82**		0.36		0.57		0.41		0.41

*p<0.05 **p<0.01 N=525 female prospective elementary teachers in 27 classes in Southern California.

was a significant independent predictor of the Creative scale, while Cooperation, Open-Endedness and Material Environment were all significant independent predictors of the Testable scale, and that Material Environment was a significant independent predictor of the Unified scale. All significant regression coefficients are positive, confirming a positive link between a favorable classroom environment and the student outcome of understanding the nature of science. The multiple correlation was nonsignificant for the Amoral scale at the individual level of analysis and for all four NSKS scales at the class level of analysis.

My findings of associations between attitudes towards science and learning environment replicate many past studies at various grade levels and in various countries (Adolphe et al., 2003; Fraser & Griffiths, 1992; Fraser, McRobbie, & Fisher, 1996; Goh et al., 1995; Khine & Fisher, 2001; Kim & Kim, 1996; Margianti et al., 2002; Soerjaningsih & Fraser, 2000; Wong et al., 1997).

5.9 Summary of Chapter

This summary addresses how the quantitative results described in the above sections of this chapter answer my research questions. The quantitative findings were derived from the survey used in my study, using scales from *What Is Happening In this Class?, Science Laboratory Environment Inventory, Test of Science-Related Attitudes*, and the *Nature of Scientific Knowledge Survey*.

5.9.1 Research Question #1

Is it possible to develop valid and reliable measures of prospective elementary teachers':

(a) perceptions of the learning environment,

(b) attitudes towards science, and

(c) understandings of the nature of science?

The results of the factor analysis, and the tests of internal consistency reliability, discriminant validity, and ability to differentiate between classrooms, provide strong evidence that valid and reliable measures of prospective elementary teachers' perceptions of the learning environment are possible. Although scales came from two different instruments, the modified survey was suitable and applicable to the design and instructional goals of SCED 401. This is supported by the fact that 43 out of the 46 items had factor loadings greater than 0.40 for either the previous laboratory course or for SCED 401 (the three items omitted from further analyses came from the SLEI), the very high Cronbach alpha coefficients for all scales, and the satisfactory discriminant validity and ANOVA results for the ability to differentiate between classrooms. In the past, both instruments were thoroughly field tested with large sample sizes, and were subsequently used by many learning environment researchers throughout a diverse cross-section of countries (Adolphe et al., 2003; Aldridge & Fraser, 2000; Dorman, 2003; Fraser et al., 1993; Giddings & Waldrip, 1996; Hofstein et al., 1996; Majeed et al., 2002; Margarianti et al., 2002; McRobbie & Fraser, 1993; Wong & Fraser, 1994). This extensive prior research and the instrument developers' attention to validity and reliability, paved a smooth road for addressing parts (a) and (b) of my first research question.

Results of the factor analysis for the *Nature of Scientific Knowledge Survey* showed that only 27 out of the 48 items had factor loadings greater than 0.30 based on their understandings before and/or after SCED 401. Two scales out of the six were entirely omitted from further analyses, namely, Parsimonious and Development. Nevertheless, the scales and items that remained revealed fairly good alpha reliabilities and discriminant validity. The highest Cronbach alpha was for the Creative scale, using the class mean as the unit of analysis (0.87 for the pretest, and 0.91 for the posttest). Because the *Nature of Scientific Knowledge Survey* was developed in 1978, some current nature of science researchers feel the survey could be obsolete (Abd-El-Khalick, personal communication), and not an ideal method for assessing the complex cognitive domain encompassed by the nature of science. Although I realized the limitations of the NSKS and felt that certain scales did not adequately describe how SCED 401 instructors were teaching the nature of science, the instrument was still the best choice for this study. In addition, subjecting the NSKS to rigorous factor analysis, and validity and reliability testing, provided valuable quantitative data to compare and blend with the qualitative data (discussed in Chapter 6).

5.9.2 Research Question #3

Are there differences between students' previous laboratory course and A Process Approach to Science (SCED 401) in terms of:

(a) perceptions of the learning environment,
(b) attitudes towards science, and
(c) understandings of the nature of science?

Dramatic gains were found on all scales measuring students' perceptions of the learning environment and attitudes towards science after SCED 401 compared to students' previous laboratory course. The greatest positive differences, in order, were seen with Open-Endedness, Investigation, Material Environment, Enjoyment of Science Lessons, and Instructor Support. Related to these large positive differences, effect sizes were also substantial: Open-Endedness–6.74, Investigation–3.77, Material Environment–3.82, Enjoyment of Science Lessons–2.98, and Instructor Support–2.98. Paired-samples *t*-tests with the modified Bonferroni procedure indicated that all learning environment and attitude scales had gains that were statistically significant ($p<0.01$). Gains were also realized with the four scales of the *Nature of Scientific Knowledge Survey*, although differences were not as substantial. The largest gain was observed on the Creative scale with an effect size of 2.05 standard deviations. The modified Bonferroni procedure indicated that differences for Creative and Unified were statistically significant. ($p<0.01$).

5.9.3 Research Question #4

How does integrating real research data on Antarctic seabirds into the course affect prospective elementary teachers':

(a) perceptions of the learning environment,
(b) attitudes towards science, and
(c) understandings of the nature of science?

For the six classes that experienced the integration of real research data on Antarctic seabirds into their course (i.e. the intervention), a small positive gain was seen for Instructor Support, and a larger gain for Material Environment with regard to the learning environment.

However, neither difference was statistically significant. The only statistically significant difference for perceptions of the learning environment was seen with Student Cohesiveness, which indicated *less* Student Cohesiveness in the intervention classes compared to the nonintervention classes. The effect size for Student Cohesiveness was 1.53 ($p<0.05$). Possible explanations for this unusual finding are discussed in Chapter 6.

Whereas the learning environment did not appear to be very different between the intervention and nonintervention classes, students' attitudes towards science appeared to be substantially different. Enjoyment of Science Lessons scores were 1.44 standard deviations higher in the intervention classes, which was statistically significant ($p<0.05$).

For the *Nature of Scientific Knowledge Survey*, the intervention classes experienced a positive gain for the two scales of Creative and Amoral but showed a negative difference for the other two scales of Testable and Unified. However, only the gain for Creative was statistically significant ($p<0.05$). As mentioned in Section 4.9.1, which summarized the validity and reliability of the instruments used in this study, the NSKS is not an ideal survey and probably does not measure contemporary aspects of the nature of science as presently taught in K-16 science classrooms. When students' pretest and posttest results were compared, a statistically significant difference was only found for two of the NSKS scales (Creative and Unified). Therefore, it was not surprising that only one scale—Creative—was statistically significant when the intervention and nonintervention classes were compared.

5.9.4 Research Question #5

Are there associations between the learning environment and the student outcomes of:

(a) attitudes towards science, and

(b) understandings of nature of science?

Associations with the learning environment were stronger for attitudes towards science than for understandings of the nature of science. This finding supports previous studies (Fisher et al., 1997; Henderson et al., 2000; McRobbie & Fraser, 1993) in which the learning environment was found to be a stronger predictor in the affective domain (attitudes and beliefs) compared to the cognitive domain (academic achievement). Simple correlations and multiple regression analyses revealed only weak associations between the four scales on the NSKS and learning environment. Using the class mean as the unit of analysis, multiple correlations were statistically significant only between learning environment and Enjoyment of Science Lessons (R=0.82, p<0.01), and *not* between learning environment and any of the Nature of Scientific Knowledge scales. While the biggest difference between students' previous laboratory course and SCED 401 involved Open-Endedness, the factor that contributed the most to students' Enjoyment of Science Lessons was Instructor Support (r=0.75; p<0.01; ß=0.87; p<0.01, using the class mean as the unit of analysis).

Chapter 6

QUALITATIVE RESULTS

6.1 Introduction and Overview

Combining quantitative and qualitative methodologies in one study has many advantages. It allows triangulation of data (Anderson, 1998; Creswell, 1994; Mathison, 1988), an examination of construct validity of learning environment/attitude scales, an in-depth understanding of learning environments from more than one perspective, and uses the idea of *grain sizes* (different-sized samples for different research questions varying in extensiveness and intensiveness) (Fraser, 1999). Greene et al. (1989) state that combining methods in a single study achieves complementarity and the appearance of overlapping and different facets of phenomena (similar to peeling away the layers of an onion).

I also felt that using a mixed-methods approach would help to answer several of my research questions. For example, my third research question is: *Are there differences between students' previous science laboratory course and 'A Process Approach to Science' (SCED 401) in terms of :*

(a) perceptions of the learning environment,
(b) attitudes towards science, and
(c) understandings of the nature of science?

In my study, a learning environment and attitude scales were used along with the *Nature of Scientific Knowledge Survey* (NSKS) to provide an initial large-scale probe resulting in an overview of differences. However, by using qualitative approaches as well (open-ended questions from the *Views of Nature Of Science*–VNOS online survey and interviews), I expanded the scope, depth and credibility of my study. Whereas the surveys included all 525 female prospective elementary teachers enrolled in SCED 401 over four semesters, the VNOS analysis involved a subsample (*n*=115 or *n*=98 depending on the semester and item analyzed). The finest grain size involved the interviews with another subsample of students (*n*=35 from my intervention classes).

My fourth research question was: *How does integrating real research data on Antarctic seabirds into a course affect prospective elementary teachers' understandings of the nature of science?* For this research question, I relied on an even finer grain size. Using a subsample of my intervention classes' students (*n*=5), I analyzed concepts maps from a question in their final examination that explicitly asked them the above research question. Concept maps are cognitive mental maps in which students construct and represent their understanding of a concept in graphical form. Because qualitative research "is the most fundamentally constructivist research method available to us" (Erickson, 1998, p. 1172), it was appropriate to use concept maps, an equally constructivist teaching and learning strategy, in my study.

My qualitative results are presented in three sections. Section 6.2—Views of Nature Of Science (VNOS) Online Survey, describes my content analyses of student responses to three of the open-ended questions from the *Views of Nature Of Science–VNOS* (Lederman et al., 2002). A comparison of students' pretest and posttest responses helped to shed light on differences in understandings of the nature of science before and after SCED 401. Section 6.3—Interviews With Students in Intervention Classes of SCED 401, deals with *themes* (Anderson, 1998; Creswell, 1994; Seidman, 1991) that were identified in the interviews with 35 prospective elementary teachers in two of my intervention classes. Section 6.4—Concept Maps on Seabird Project and the Nature of Science, illustrates through a graphical representation how five prospective elementary teachers in my intervention classes perceived the influence of the Seabird Project in shaping their understanding (or lack of understanding) on the nature of science. Lastly, Section 6.5 provides a summary of the chapter and reiterates the main findings as they relate to my research questions. Overall, I found that the qualitative data analysis supported the strong construct validity of all the learning environment and attitude scales, as well as one of the *Nature of Scientific Knowledge Survey* scales. My analytic charts in this chapter identify key patterns in the forest (Erickson, 1998), while both typical and atypical quotes allow the reader to see the trees.

6.2 Views of Nature of Science (VNOS) Online Survey

The majority of researchers in the field investigating students' and teachers' conceptions of the nature of science use an open-ended response instrument called *Views of Nature Of Science—VNOS, Form C* (Lederman et al., 2002). The VNOS is typically used with very small samples due to the amount of written material generated by the 10 questions, and because the developers highly recommend interviewing participants, as well, in order to confirm understanding of the questions and to elaborate student responses by asking probing questions.

During the spring semester of 2003, Items #1 and #2 (see Figure 4.1) from the VNOS were placed on the Science Education Department's website. The link was available to students for only one week. I visited all eight classes of SCED 401 on the first day of the course, and gave out the learning environment/attitude questionnaire and the *Nature of Scientific Knowledge* Survey—NSKS. The learning environment questionnaire assessed their perceptions of their previous laboratory course, the attitude scale measured their Enjoyment of Science Lessons during their previous laboratory class, and the NSKS served as a pretest to assess their understandings of scientific knowledge based on *all* of their previous science education experiences. I also asked students to go online over the next couple of days to answer the two VNOS questions (therefore, this was a homework assignment that students did in their own time). During the last week of the semester, I visited all classes of SCED 401 again to administer the learning environment/attitude survey and the NSKS to students. This time, students completed the surveys with SCED 401 in mind. I also informed them that the two VNOS questions were again posted on the website. Rather than leaving it to the students' own initiative to answer the questions at this busy and hectic time of the year, I set up in each classroom a dozen laptop computers that had remote access to the Internet. After students had filled out the learning environment/attitude and NSKS surveys, they went online and answered the VNOS questions that same day.

During the fall of 2003, the same procedure described above was carried out but this time, Items #3 and #4 from the VNOS were used (see Figure 4.1). For the content analyses of students' responses in the spring and fall 2003 semesters, I matched each student's pretest and posttest response. However, because students' pretest responses were completed as a homework assignment, and because all instructors did not consistently remind their students to do the assignment, I was able to match only about 50% of each semester's total female enrollment in the course. For the spring 2003 semester, this resulted in 115 matches and, for the fall 2003 semester, 98 matches were made.

Developers of the VNOS analyze each participant's pretest and posttest response, in order to assign one of three possible ratings—naïve, informed, or no category. After comparing pretest and posttest responses, a decision is made whether the participant made any improvement or growth in their understanding on the nature of science. Decisions are also cross-checked during interviews. Understanding, or lack of understanding, of the nature of science is based on eight 'aspects' or descriptions of science proposed by Lederman et al. (2002). The eight aspects include tentativeness, empirical basis of science, subjectivity, creativity and imagination, sociocultural embeddedness, the use of both observations and inferences, the distinction between laws and theories, and the lack of a single scientific method. However, Lederman et al. (2002) point out that there is not a one-to-one correspondence between each VNOS item and each of the eight target nature of science aspects. Lederman et al. (2002) and Schwartz et al. (2004) also stress that "none of these aspects can be considered apart from the others" (Schwartz et al., 2004, p. 613) and, therefore, all ten questions from the VNOS should be used.

In my study, however, I did not follow Lederman et al.'s (2002) protocol. Because I had a relatively large sample size of 525, and because I was also using the *Nature of Scientific Knowledge Survey—NSKS* (Rubba & Anderson, 1978), I decided to use only four questions that, at one point in time, I felt corresponded with scales on the NSKS. I also did not conduct interviews with students to confirm their understanding of each VNOS item. After reading many of the matched pretest and posttest responses, I decided to reduce my content analysis to only three of the four questions. I felt that analyzing Item #1 "What, in your view, is science"? was too broad and, in fact, did *not* correspond very closely to any of VNOS' eight aspects on the nature of science, or to any of the scales on the NSKS. I also did not want to be limited to categorizing students' responses as simply naïve, informed, or no category. I was more interested in how the entire subsample from each semester answered the questions in order to produce analytic charts and identify patterns in the forest. Lederman et al.'s (2002) and Schwartz et al.'s (2004) approach is to closely examine a few individual trees. Still using Lederman et al.'s (2002) research as a guideline, however, I analyzed each response and identified how many times misconceptions were stated (a naïve response), and also I reported on common themes (Anderson, 1998; Creswell, 1994). Misconceptions and common themes were then compared between the pretest and posttest responses using the 'constant comparative method' (Glaser & Strauss, 1967). Representative quotes from students were extracted as examples. These served as detailed evidence or 'particular descriptions' (Erickson, 1998) of patterns and themes. Findings from my content analysis are provided under the following three sections corresponding to each of the three VNOS items that I analyzed.

- ☐ Section 6.2.1—Creativity and Imagination in Scientific Investigations
- ☐ Section 6.2.2—What is an Experiment?
- ☐ Section 6.2.3—Theories and Laws

6.2.1 Creativity and Imagination in Scientific Investigations

The first VNOS item that I analyzed was:

> Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?
>
> - ☐ If yes, then at which stages of the investigations do you believe scientists use their imagination and creativity: planning and design, data collection, after data collection? Please explain why scientists use imagination and creativity. Provides examples if appropriate.
> - ☐ If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if appropriate.

According to Lederman et al. (2002), novice nature of science learners (defined as 'naïve') feel that creativity and imagination are not integral to science. In addition, they reported that novices believe in a single scientific method, and this belief often becomes apparent in their responses to this item. Interestingly, however, I did not find any of the 115 prospective elementary teachers who responded to this question in the spring of 2003, mentioning a single or step-by-step scientific method in either their pretest or posttest response. Lederman et al. further reported that novices feel that "most creativity in science occurs during conjecturing and before the scientific method is employed" (Lederman et al., 2002, p. 508), presumably during 'planning and design' as stated in the actual VNOS question.

Qualitative research emphasizes uncovering *kinds* of events or factors that make a difference. In my study, I was interested in science learning for prospective elementary teachers. "This priority of emphasis does not mean that information about frequency is irrelevant of qualitative inquiry, for good qualitative research reports the range and frequency of actions and meaning perspectives that are observed…." (Erickson, 1998, p. 1155). Keeping Erickson's advice in mind, I summarized in Table 6.1 the pretest and posttest responses given by the 115 female prospective elementary teachers during the spring semester of 2003. The most striking and heartening aspect of the analysis is that, contrary to Lederman et al.'s findings, very few of the teachers felt that scientists use no imagination and creativity during investigations (only 3.5%) even at the time of pretesting. This was reduced to zero during the posttest.

Table 6.1
Summary of Pretest and Posttest Responses to the VNOS Question on Imagination and Creativity During Investigations

Description of Response	Pretest		Posttest		% Difference Between Pretest-Posttest
	No. of responses	%	No. of responses	%	
No, scientists do not use imagination and creativity during their investigations.	4	3.5	0	0	–3.5
Yes, scientists use imagination and creativity during all three stages of their investigations—planning and design, data collection, after data collection.	37	32.2	52	45.2	+13.0
Yes, scientists use imagination and creativity during investigations, but only during two stages.	8	6.9	15	13.0	+6.1
Yes, scientists use imagination and creativity during investigations, but only during the planning and design stage.	31	26.9	25	21.7	–5.2
Yes, scientists use imagination and creativity during investigations. (But response was unclear about which stage or stages.)	31	26.9	20	17.4	–9.5
Answer mentioned that imagination and creativity were needed to '*prove*' something (e.g., to prove a theory).	11	9.6	3	2.6	–7.0

n=115 female prospective elementary teachers enrolled in SCED 401 during the spring semester of 2003 at California State University, Long Beach.

Because there were only four students who felt that no imagination and creativity is needed during investigations when they began SCED 401, it is interesting to look at why they said this and to make comparisons with their responses after they completed the course. Again, Erickson (1998) advises us not to ignore disconfirming evidence, anomalies, or atypical responses as they “need to be reported if the report is not to be one-dimensional and superficial” (p. 1168). The responses of three students who said ‘no, imagination and creativity are not needed during scientific investigations’ during the pretest are shown below (each from a different instructor’s class).

> *Student 1—PRETEST:* No, because I think that scientists use their knowledge and intelligence when performing experiments.
>
> *Student 1—POSTTEST:* Yes, scientists use their creativity when trying to test their hypothesis. Creativity is very crucial to differentiate their study from other scientists. I believe that creativity must be used in every step a scientist takes. Imagination must be used to create a distinct experiment that will derive an answer they are trying to find, whether it is proving or disproving an idea.

> *Student 2—PRETEST:* No, I do not think they use their creativity, but their curiosity. Curiosity is what gets scientists ‘going’. Then, they start to wonder how things work or what happens after ‘X’ happens.
>
> *Student 2—POSTTEST:* Yes, scientists can use various objects and use different ideas as well as areas of knowledge when conducting their experiments. They also use objects that normally the ‘common’ person would not think about like crayons, legos, etc. Scientists like to find simple solutions to problems.

> *Student 3—PRETEST:* No, I believe that scientists don’t use creativity because they are simply following a set of laws. Usually, they are performing experiments simply to prove or disprove an existing theory.
>
> *Student 3—POSTTEST:* Yes, scientists have to be creative when designing their experiments and also when making conclusions. They have to find creative ways of collecting their data because they need to find a variety of data to collect.

On the pretest, 32.2% of the teachers believed that scientists use imagination and creativity during all three stages of investigation—planning and design, data collection, and after data collection—and this increased to 45.2% on the posttest. Although a 13% increase can be considered a positive sign, this still leaves over half of the prospective elementary teachers with a lack of understanding that scientists use creativity and imagination at all stages of an investigation, even after completing SCED 401. A student who said ‘yes’ for all three stages on both the pretest and posttest said this during her pretest:

> *Student 5—PRETEST:* Yes, imagination and creativity are needed at any stage of an investigation. Just like an FBI agent on the job, a scientist must investigate and think in creative ways that others might not have thought about in order to crack an important case.

Surprisingly, only two students from the spring 2003 intervention classes used any explicit examples from the Antarctic Seabird Project during their posttest response to illustrate how scientists use imagination and creativity. One of the students said that imagination and creativity were needed for all three stages on both her pretest and posttest response, while the other student mentioned all stages on her pretest, but only mentioned planning and design and data collection on her posttest. The responses given by the two students who explicitly mentioned something about the Seabird Project during the posttest are provided below.

> *Student 6—POSTTEST:* Yes, scientists use their creativity at the planning and design as well as when collecting data. For example, when Dr. Peter Hodum *[the wildlife biologist who collected the seabird data]* was trying to find where the seabirds flew off to he had to think of a way not to influence their normal behavior but still be able to obtain his data. Thus, *[that's]* why he used the tracking device only for a certain period of time and he made sure that the weight of it would not be so large that it would affect the bird's ability to fly long distances.

> *Student 7—POSTTEST:* Yes, scientists must be creative in order to collect data, for example, when Dr. Hodum had to figure out ways in which to measure seabirds which were living in burrows. He had to find a creative way to measure them without disturbing them and without taking up too much time and work.

On the pretest, an equal number of teachers (26.9%) felt that scientists use imagination and creativity *only* during planning and design, or were not clear about at which stage or stages. This percentage decreased similar amounts on the posttest—21.7% still felt only the planning and design stage required imagination and creativity, and 17.4% were still unclear about the stage. Lederman et al. (2002) reported that all of their 'novice' respondents believed that most creativity in science occurs before the scientific method is employed (i.e., only during the planning stage). Considering they validated the VNOS with nine people holding doctoral degrees in fields such as American literature, history, and education, the prospective elementary teachers did very well on both the pretest and posttest. Two pretest responses of students who said imagination and creativity are only needed during planning and design are provided below.

> *Student 8—PRETEST:* Yes, certainly scientists are intelligent people. I believe that they use creativity during the planning and design stage. Science also limits creativity for accurate records have to be kept and there isn't any room to do extra things. *(This student said that all three stages require imagination and creativity on her posttest.)*

> *Student 9—PRETEST:* Yes, I think scientists do use their creativity during planning and design of their experiments. I think that creativity during actual data collection and after would most likely corrupt

> data results. *(This student still said only the planning and design stage requires imagination and creativity during her posttest.)*

Lastly, a common misconception exists that scientists try to *prove* something during their experiment or investigation, or to *prove* a hypothesis, theory or law (Désautels & Larochelle, 1998; Lederman, 1992). Consequently, I recorded the responses that used the words '*prove', 'proof',* or '*proving'* and found that 9.6% of students used these words during the pretest, and this was reduced to 2.6% on the posttest. Unfortunately, this does not *really* mean that only 2.6% of the students believe that things must be proven in investigations, as was shown in the content analysis of the third VNOS item. This notion of proof, nevertheless, is a common connecting thread (Erickson, 1998) in responses to all three VNOS items.

6.2.2 What is an Experiment?

Lederman et al. (2002) found that participants answered Item #3 'What is an experiment?' in broad and general terms (e.g., "procedures used to answer scientific questions", p. 510). In addition, novice participants said that experiments aim to prove or disprove hypotheses or theories, and must follow a single scientific method. With Lederman et al.'s findings in mind, I identified five themes or categories (Anderson, 1998; Creswell, 1994; Erickson, 1998) that emerged from the responses of 98 prospective elementary teachers who answered this question during the fall semester of 2003.

In Theme 1, students stated that experiments 'test results, a hypothesis, educated guess, or theory'. I felt these responses represented naïve conceptions, particularly because the majority of responses in Theme 1 mentioned 'testing a hypothesis or educated guess', a likely 'knee jerk' answer with no understanding of the purpose or definition of hypothesis (an assumption on my part). Theme 2 responses were still broad and simplified, although I felt that they were slightly better than Theme 1 responses. In Theme 2, students stated that experiments 'test or investigate a researchable question, idea, prediction, curiosity, or support/refute a hypothesis'. The vast majority of responses in this category explained that experiments answer or investigate researchable questions. In Theme 3, students said that experiments involve 'a process', such as observing, relating, communicating, comparing, problem-solving, or analyzing or investigating. This, no doubt, reflects the influence of the course title (*A Process Approach to Science*), and the considerable emphasis in the course on the processes of science by all instructors. Most students said that experiments involved 'a process of analyzing or investigating' in Theme 3. In Theme 4, I recorded three common misconceptions—the necessity of proof in experiments, a step-by-step procedure or rigid scientific method, and an objective and unbiased viewpoint (Désautels & Larochelle, 1998;; Lederman, 1992; Lederman & O'Malley, 1990). The majority of responses that fell into Theme 4 mentioned the first two misconceptions. Lastly, Theme 5 included a discussion of the qualities of a good, traditional experiment, and would correspond to Lederman et al.'s 'informed' response. In simplest terms, an experiment can be defined in the following way: "A type of research that randomly assigns subjects/objects to a control group and an experimental group and compares outcomes" (Anderson, 1998, p. 251). In this theme, students mentioned one or more of the following: random samples, an organized plan, no one scientific method, control versus experimental groups, controlling variables, repeatability, many trials, gathering evidence or data through observations, quantitative versus qualitative data, and science as a social endeavor. Identification of these five themes as discussed in the prospective elementary teachers' pretest and posttest responses are summarized in Table 6.2. Because content analysis of this question was not as straight forward as the previous VNOS question dealing with imagination and creativity in investigations, I performed the analysis twice, and took the average of the two scores to present in Table 6.2. Also note that the percentages do not total 100% because students could, and quite often did, mention more than one theme in a response.

The most salient result of the content analysis is the 46% improvement in Theme 5 representing the qualities of a good, traditional experiment, or an 'informed' view of experiments. Approximately 50% of the 'informed' responses came from my intervention classes (two out of the nine classes), but this in part could be due to the fact that my students represented the greatest percentage of respondents in the first place. Two students in my intervention classes indicated naïve and vague definitions of an experiment during their pretest, but made considerable improvements in their posttest responses as shown in the following quotes:

> *Student 10—PRETEST:* An experiment is something a scientist does to test or prove a hypothesis.
>
> *Student 10—POSTTEST:* An experiment is the investigation of a researchable question. It can mean comparing a control and an experimental group, where all of the variables remain the same except for

> the experimental variable. The experimental variable is only given to the experimental group. For example, we did the plant experiment in which our experimental variable was Super Bloom *[a fertilizer]* and we tested to see if Super Bloom impacted the growth of the Impatiens plants, which it did.

> *Student 11—PRETEST:* I think an experiment is a mixing combination of ideas and concepts taken into action to get a product.

> *Student 11—POSTTEST:* An experiment is a form of investigating a researchable question. An experiment has a control group and an experimental group, where the only difference is the one variable chosen for the experimental group. An experiment must be performed a series of times to ensure the credibility of the experiment's result.

Table 6.2

Summary of Pretest and Posttest Responses to the VNOS Question 'What is an experiment?'

Theme	Pretest		Posttest		% Difference Between Pretest-Posttest
	No. of Responses	%	No. of Responses	%	
1—An experiment is a test of results, a hypothesis, educated guess, or theory.	44.5	45.5	19.5	19.5	–26.0
2—An experiment is a test to answer or investigate a researchable question, to support/refute a hypothesis, or to test an idea, prediction or curiosity.	23.5	24.0	42.5	43.5	+19.5
3—An experiment is a process such as analyzing/investigating, relating, observing, communicating, or problem-solving.	4.5	4.5	15.5	15.5	+11.0
4—An experiment is done for 'proof', is a step-by-step procedure or rigid scientific method, &/or must be objective/unbiased.	28.5	29.0	20.0	20.0	–9.0
5—A description of several qualities of a good, traditional experiment encompassing an 'informed' view.	15	15.0	60.5	61.0	+46.0

n=98 female prospective elementary teachers enrolled in SCED 401 during the fall semester of 2003 at California State University, Long Beach. Numbers and percentages were calculated by taking the average of two completely separate content analyses.

Student 10 mentions “prove a hypothesis” in her pretest, but she has a very sophisticated and detailed posttest response. Her example of using Super Bloom in the plant experiment arose because the student groups are given eight *Impatiens* plants on the second day of class, and simply told to conduct an experiment testing a variable that they think will promote growth. I discuss control and experimental groups in general terms, and then leave the rest of experimental decisions up to the students. This activity is an example of ‘guided inquiry’ (Colburn, 2000) where the materials and topic/problem is provided, but the students devise their own procedures. The students take measurements on a weekly basis over a two-month period, and then write up a report in groups of two or three students.

It is also significant that Theme 1, the over-simplified response that ‘an experiment is a test of results, or a hypothesis, educated guess, or theory’, is reduced by 26% on the posttest. Unfortunately, however, 19.5% still provided this kind of a definition for their posttest response, and 20% still stated a misconception such as ‘an experiment is done for proof, is a step-by-step procedure or rigid scientific method, and/or must be objective and unbiased’. Lastly, Table 6.2 indicates a 11% increase in the posttest responses of words/phrases associated with the processes of science—analyzing, investigating, relating, observing, communicating, or problem-solving. It is difficult to say whether this is a positive or negative result because, from a certain perspective, an experiment *is* a process.

6.2.3 Theories and Laws

Of the three VNOS questions analyzed, the question regarding theories and laws seemed the most challenging for the prospective elementary teachers. Specifically, this item asked ‘Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example’. Relatively little change was observed between pretest and posttest responses. A common misconception was that laws have a higher status than theories because theories have not been proven, while laws have been proven (Lederman et al., 2002: Schwartz et al., 2004). Closely linked with this misconception is the notion that theories can change while laws are set in stone and cannot change. A content analysis of responses, including these misconceptions, are provided in Table 6.3.

Although only a small number of the 98 prospective elementary teachers said that theories become laws once theories have been proven (4.1%) during the pretest, this did not change significantly on the posttest (+5.1%). On the pretest, 10.2% of the prospective teachers said that theories can change but laws cannot change, and this was reduced to 5.1% on the posttest. The most dramatic finding resulting from the content analysis of this item, however, is that close to half of the prospective teachers (46.9%) believed that theories have not been proven yet, while laws have been proven. Considerable improvement was made on the posttest, although 30.6% still believed laws have been proven, leaving ample room for improvement.

Table 6.3

Summary of Pretest and Posttest Responses to the VNOS Question About Theories and Laws

	Pretest		Posttest		
Description of Response	No. of responses	%	No. of responses	%	% Difference Between Pretest-Posttest
No, there is no difference between a scientific theory and a scientific law.	1	1.0	9	9.2	+8.2
Scientific theories and scientific laws are ‘similar’.	3	3.1	2	2.0	–1.1
Theories become laws once theories have been proven.	4	4.1	5	5.1	+1.0
Theories haven’t been proven yet, while laws have been proven.	46	46.9	30	30.6	–16.3
Theories can change but laws cannot change (laws are set in stone).	10	10.2	5	5.1	–5.1
A correct definition was provided for both scientific theories and scientific laws (with no misconceptions contained in the response).	0	0	9	9.2	+9.2

n=98 female prospective elementary teachers enrolled in SCED 401 during the fall semester of 2003 at California State University, Long Beach. The question was “Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.”

The extent of the prospective elementary teachers' challenge to define theories and laws can be seen with how many students successfully explained the difference between theories and laws. None of the responses on the pretest, and only 9.2% on the posttest, can be considered correct definitions. Schwartz et al. (2004) clarify that: "Laws describe relationships, observed or perceived, of phenomena in nature. Theories are inferred explanations for natural phenomena and mechanisms for relationships among natural phenomena. Theories and laws do not progress into one and another, in the hierarchical sense, for they are distinctly and functionally different types of knowledge" (p. 613). Theories often explain laws. Theories are robust, well-supported explanations based on substantial evidence, and "provide a framework for current knowledge and/or future investigations" (Lederman et al., 2002, p. 507). Lederman et al. explicitly state that scientific theories are "nonobservable inferred explanations" while laws are "descriptions of observable phenomena" (p. 507). The discrepant responses stand out from the 90.8% of the responses that were vague and confusing. Examples of how the prospective elementary teachers worded their definitions are provided below (each from a different instructor's class):

> *Student 12—POSTTEST:* Yes, I think there is a difference between a scientific theory and a scientific law. A scientific law is usually a statement that identifies a particular occurrence/situation. For example, the universal law of gravity states that all objects fall at a constant rate, regardless of its weight or mass. A scientific theory, on the other hand, is an explanation for a particular situation/occurrence. For example, the Theory of Evolution states that man slowly evolved from the first living organisms on earth. In summation, a law states WHAT happens and a theory explains WHY something happens.

> *Student 13—POSTTEST:* A scientific law is knowledge that describes relationships observed in nature and is widely accepted to be true for all cases. A scientific theory is an inferred explanation for natural phenomena (i.e., an explanation for why something is happening as observed). Theories often explain laws. Both are tentative and subject to change. An example of a law would be 'what goes up must come down' according to Newton. Gravity makes sure that an object that goes up is pulled back down. An example of a theory is that strong gusts of wind travel in one direction. It is only an inference that someone thinks up from their knowledge.

> *Student 14—POSTTEST:* The difference between a law and a theory is that a law simply states what something does, but it does not try to define *why* it does what it does. A theory more or less tries to define *why* things happen and it does not ever become a law. They stay as theories.

Although these students are still struggling to define and describe concepts that are no doubt difficult for them to comprehend, there are segments in their responses that indicate they are trying to apply what they have learned in the course. However, here is an example when interviewing these three prospective teachers as recommended by Lederman et al. (2002), could have provided interesting insights on whether they truly understood the difference between theories and laws or whether they were simply ‘parroting’ something an instructor had said in class. Is it any wonder that the prospective elementary teachers are still confused over the meaning of theories and laws, even after taking SCED 401, particularly when we review the definitions? I feel that knowing the difference between theories and laws is not necessary anyway for my students’ future elementary science children. I believe the problem with these terms is embedded with how we use them in everyday language. Although the VNOS question specifically said *scientific* theory and *scientific* law, most of the time we think of these words in an everyday, nonscience context. The two quotes below provide evidence of this:

> *Student 15—POSTTEST:* The difference between a scientific theory and a scientific law is that the scientific theory is a guess based on some tests but it has not been tested many times in order to become a law that can be proven. An example of this is like in the government, when a bill is introduced as an idea that someone has but that idea needs to go through many different people in order to become a law.

> *Student 16—PRETEST:* There is a difference between scientific theory and scientific law because a theory is an idea that has been tested once but is not known to be true completely. A scientific law is a theory that has been tested over and over again by different sources and there has been a consistent nature of the theory which later becomes a law but it is not an absolute law. An example of this would be an opinion of a movie that is said by one person to be a theory, but when it is later seen by many more people, and people have a common theory. Then, it becomes more popular and it is like a law.

Again, we see the thread of ‘proof’ in Student 15’s response, while Student 16 believes that laws have higher status than theories. Certainly, prospective elementary teachers hear and discuss laws in the context of governance and societal ‘law and order’, much more than in the context of *scientific* laws.

The three VNOS questions placed a different cognitive demand on the prospective elementary teachers in comparison to the *Nature of Scientific Knowledge Survey*—NSKS. Whereas the NSKS was a standardized, convergent paper-and-pencil instrument with questionable validity (for some scales), the VNOS’ open-ended response format allowed me to “identify the nuances of subjective understanding that motivate various participants” (Erickson, 1998, p. 1155). Nevertheless, 525 prospective elementary teachers completed the NSKS, and this allowed a statistical deductive analysis that, in turn, complemented the analytic inductive process (Lindesmith, 1947) undertaken with the VNOS. Thus, I discovered, post hoc, the opinions, beliefs, and understandings about the nature of science among a large subsample of the prospective teachers.

6.3 Interviews With Students in the SCED 401 Intervention Classes

During the fall semester of 2003, I interviewed 35 female students enrolled in my two classes. The two classes represented 22.2% of the total enrollment of students in SCED 401 during the fall of 2003 (or 7% of the total sample size). All instructors conduct exit interviews or oral examinations during the last week of classes. Consequently, it was fairly easy for me to ask a few extra questions that pertained to my study (after receiving their verbal permission) and to audiotape their responses. I conducted the interviews with students in pairs, as I had discovered during past exit interviews that this alleviated some of the students' anxiety over this relatively new assessment strategy, and students tended to be more descriptive and animated when sitting beside a friend. Further details of the procedures which I followed when conducting these interviews were described in Chapter 4—Research Methods. However, I wish to remind the reader that not all 35 students were asked all six questions (see Appendix C). Due to time constraints, I alternated between questions and, therefore, each student was asked at least three questions. However, I also explained that the other person was welcome to volunteer a comment, say something different, or give another example in reference to her partner's question.

After analyzing the 100 pages of transcribed audiotaped interviews, I identified five themes (Anderson, 1998; Creswell, 1994; Seidman, 1991) that encapsulated the 35 prospective elementary teachers' responses. The themes correspond to the actual interview questions, although responses to Item #4—What did you think of the investigations and experiments that we did in this course? How did the investigations and experiments in your previous science laboratory course compare with this course? were enveloped in the five other questions' themes. The five questions, along with a description of the themes, are provided in the following subsections and are titled:

- ❑ Section 6.3.1—Open-Endedness—The Abyss Between Previous Laboratory Courses and SCED 401
- ❑ Section 6.3.2—Student Grouping ≠ Student Cohesion or Cooperation

- Section 6.3.3—Like the Three Bears Story—‘It Was Just Right’
- Section 6.3.4—Authenticity Leads to Understanding the Nature of Science
- Section 6.3.5—Attitudes Towards Science

6.3.1 Open-Endedness—The Abyss Between Previous Laboratory Courses and SCED 401

Question #1 asked “What was the biggest difference between your *previous* science laboratory class and this course?” The majority of students overwhelmingly said things that were related to the Open-Endedness learning environment scale (although, at this point in the interview, students did not explicitly use the word ‘open-ended’). They talked about their previous laboratory class having preset directions or procedures, being convergent with everyone getting the same answer to experiments and investigations, a dearth of hands-on activities, little connection between material covered in lectures and laboratory activities, and content that was not relevant to their lives or their future careers as elementary school teachers. It did not seem to matter which previous laboratory class they were talking about, or whether it was taken at California State University, Long Beach or at a community college before transferring to the university. This finding strongly supports the quantitative results from the learning environment survey that indicated the biggest difference between students’ previous laboratory course and SCED 401 was related to Open-Endedness ($p<0.01$, effect size of 6.74 standard deviations). The following quotes are representative of the responses I received for this question:

> The biggest difference…was a lot of hands-on and no minds-on. You didn’t really think about what was going on. It was just read this physics lab and follow the procedure.

> Things were more convergent with just one right answer…the lecture was totally opposite to what we were learning in the lab. Yes *[the lecture and lab]*, they were in different rooms, different teacher and different lab instructor, not the same teacher like we have with you.

> We had a laboratory once a week and in my laboratory class it was totally a convergent way of thinking—the directions were all on the board the second we walked in. I was thinking what is the point of me doing this if everybody already knows the answer. So I found myself speeding through it just to get it done so I could get out of there. This class *[SCED 401]* was very divergent. We were given our experiment but we weren’t told how to do it, we weren’t told an order, we weren’t told what we should come up with at the end. It was basically here you go, have fun, tell me what you think and then describe the processes.

> She did the lecture at the beginning and we did a little bit of hands-on with the rocks and with maps at the end of the course. While in this course *[SCED 401]* we basically did the activities first and then we went on to the content after the activity which, for me, was new. It made me understand the knowledge better when I did the activity first and then the content, compared to my last lab class where it was just content and then a little bit of activity.

> I felt I learned more coming out of this class compared to the other classes which were just lecture, lecture, lecture, lecture, lecture. You come out of the class, take the test, and forget everything.

> I think the biggest difference was that, in the last course, we did more book work and it was more memorization of laws and theories, velocity and other terms and definitions. It was scientific stuff that I couldn't relate to my personal life.

> This particular course *[SCED 401]* relates to us a lot better because in our other courses they weren't geared to people wanting to be teachers. They were just general education science courses. They did not relate to us in the real world or to teaching science in the elementary classroom.

> With this class *[SCED 401]*, we were able to do our own experiments. We weren't given a data sheet. In the other class, we had a set of instructions that we had to do and we really just did them and left the class and that's all we did. *[In SCED 401]* I think we had more power over our experiments this way then just having a right or wrong answer. I know with our plant experiment that some things went wrong but we learned from that.

These voices from female prospective elementary teachers are clearly saying what many science educators have been advocating for a long time—science content courses must be specifically designed for future elementary teachers. Indeed there seems to be an abyss between students' previous laboratory courses and SCED 401. In their own words, prospective elementary teachers said that previous courses were "lots of hands-on but no minds-on, convergent, book work, rote memorization, irrelevant to personal lives, too much lecture, and a place to forget everything". There is little point in requiring students to take more and more courses, particularly when we know that the more hours of traditional science courses taken by students, the more negative their attitudes are towards science and the lower is their confidence level about teaching science to children (Stepans & McCormack, 1986). These quotes succinctly say that prospective elementary teachers want to make their own decisions about how to conduct experiments and investigations, and that they want to experience meaningful and relevant learning in their science courses.

6.3.2 Student Grouping ≠ Student Cohesion or Cooperation

For Item #2, I asked "Did you have cooperative learning groups in your previous science laboratory course? *(If yes…)* How did the cooperative learning experience in this course compare to your previous science laboratory course?" I was interested in responses to this question because I knew that students predominantly worked in groups in the majority of laboratory courses. Yet I knew from previous exit interviews that something unusual (but positive) occurred in SCED 401 groups. I hoped to pinpoint what that difference was. At the same time, results from my learning environment survey indicated that my intervention classes had statistically significantly *less* Student Cohesiveness (d=1.53, p<0.05) compared to the nonintervention classes. I was perplexed by this, and wanted insights into my students' perceptions of factors related to student cohesiveness.

After analyzing the transcribed interviews, it was confirmed that students' previous laboratory classes did have groups, but that they were rarely cohesive or cooperative. Most students spoke very fondly of their partners in SCED 401. Sample quotes are provided below:

> No, we didn't *[have cooperative learning groups in my previous laboratory class]*. We would just pair up…there were so many lab stations and two or three people had to work together. You basically just worked towards getting answers and getting all the work done and making sure you handed in that lab. But we never really communicated together and said, what we think of this. I wouldn't consider it cooperative learning.

> In SCED 401, I really felt more like it was a team effort and we were really trying to figure things out. Whereas, in *[previous lab class]* it was more just a means to an end. We're just going to work together to make sure we get this. In SCED 401, it was more cooperative—we're learning together to learn from each other.

> They gave us exactly what they wanted us to do and we just broke it up. We never really did it as a group. It was more like, I'll do this part, you do this part, and we'll get together at the end. But in SCED 401 we actually worked together on everything as a group. Whatever I didn't understand, somebody helped me understand and so we helped each other. In our class *[SCED 401]*, we're kind of friends now, and we still talk out of class, and its really nice, but different.

> I think the teacher makes a difference. We had to wait until he *[previous laboratory instructor]* was done with that, and then he would come over to us and help us out. In the end it kind of seemed like he ended up doing the lab and we just kind of watched him.

> *[Previous laboratory class]* Basically you were on your own. In SCED 401, it was different…a different environment and I felt more, how can I say it, it was more comfortable to learn. You weren't ashamed of asking someone else the same thing. Even in the very beginning of the semester, when we

> did the *[ice-breaker]* activity, I really liked doing the warm-up, getting to know each other. So that kind of bonded us together and it really made us open to discuss questions, or maybe problems that we had.

These prospective elementary teachers seem to understand the difference between being in a group versus cooperative learning. Kagan (1992) emphasized that true cooperative learning must have positive interdependence, simultaneous interaction, and equal participation, but many instructors, at all levels, do not understand this distinction. In previous laboratory classes, the students mentioned rushing through activities in order to get out of class as quickly as possible, and also breaking up work into smaller parts. But little discussion occurred to synthesize the material on which the group was working. In contrast, the above quotes indicate that SCED 401 *encouraged* student discussions, bonding, friendships, asking questions, and teamwork. Particularly illuminating was the statement in the last quote—"In SCED 401, it was different…a different environment…it was more comfortable to learn."

In the following quotes, several students discussed the importance of the physical layout of a classroom/laboratory. This is definitely a legitimate point considering an off-shoot of learning environments research called 'semiotics' interprets the hidden messages behind desk/table arrangements, visual presentations, student displays, and other interesting physical characteristics of a classroom. Shapiro (1998) explains: "Semiotic studies are based on the assumption that one's culture provides a set of signs, symbols and rules about interaction that are used, whether consciously or not, both to create and read the learning environment" (p. 609). The following two responses allude to the impact of desk arrangement on student cohesiveness and cooperation:

> In my last laboratory class, there were bench tables and so you weren't looking at the person next to you. And it wasn't always encouraged that we work together in groups.

> My group during SCED 401 worked well together. We sat at a table together. And in that *[previous lab]* class, it was designed a little differently, in rows and stuff. The design even helps out a lot having you in tables of four.

With regard to why the intervention classes had significantly less Student Cohesiveness, a couple of the students did acknowledge the existence of tension in their group, as illustrated in the following quotes.

> Unfortunately, this semester we had a lot of trouble in our group. I don't know if it was just chemistry or possibly everyone being on edge. With us there's a lot of changes going on. We have the California Standards Education Test (CSET) and Grade Point Averages (GPA), and an impacted credential program. So I think everyone is on edge. That's the best explanation I have for it. *[Researcher: "So you feel your cooperative learning group wasn't all that cooperative because of the things you mentioned?"]* Yeah, because of the personal conflicts. Overall, we did in the end still learn what we needed to learn. The problems were a growing experience and everyone learning about teamwork.

> In this class, I felt like we had a much stronger group because everybody was actively involved. There was one person we had issues with…. We just all seemed to sort of mesh and get the work done, even with the one problem that we had. I didn't feel that I let it hold me back. I just said you know what, it's going to happen, it's going to happen in my classroom, it's going to happen in any job I ever hold. I just have to be above that and work through it.

These mature and reflective comments on personal conflict were interesting. However, I could not help but believe that surely such tensions must exist in the other instructors' classes as well. All prospective elementary teachers were hit with state government changes requiring them to pass a state-mandated and state-developed, multiple-choice examination (CSET) across multiple subjects before they can receive their elementary school teaching credential and be allowed to secure a position. Upon my own personal reflection on my classes' lower Student Cohesiveness compared to the nonintervention classes, I realized that I was the only instructor who required students to write up two of the larger reports/assignments in groups of two or three. Could this explain the intervention classes' statistically significant lower score for Student Cohesiveness? I think that students were content to work in cooperative learning groups in class but, when it came to assessment, that was another issue. Could the anxiety of writing up an assignment with one or two other people, which invariably occurs no matter who the people are, affect my students' perceptions of Student Cohesiveness? My original intent was to emphasize that scientists often collaborate and write reports and articles as a team (of course, I must acknowledge that there is a difference between a working scientist's world and a university environment). The two assignments were indeed large and accounted for 40% of the students' overall grade for the course. In the light of today's educational climate of standardized testing, high GPAs, and changes to the state's elementary teacher credentialing process, I might need to reconsider requiring students to write reports in groups of two or three. On the other hand, Fraser et al. (1995) found that high scores for Student Cohesiveness lead to more favorable attitudes. Although my intervention classes had less Student Cohesiveness compared to the nonintervention classes, they had statistically significantly ($p<0.01$) more positive attitudes towards science compared to the nonintervention classes.

6.3.3 Like the Three Bears Story—'It Was Just Right'

For the third interview question, I showed the student the learning environment survey again and pointed out the items in the Open-Endedness scale. I wanted them to understand what was meant by Open-Endedness, even though I had discussed the word several times during the course. Then I asked the student: "Would you have preferred more, less, or the same level of open-endedness in this course? Can you explain why you feel this way? How did the level of open-endedness in your previous science laboratory course compare with this course?" Whereas, in Item #1, I left it open to the students to tell me what the biggest difference was between their previous science laboratory class and SCED 401, in this question, I explicitly asked them about open-endedness. As the quotes showed in Section 6.3.1, although students did not use the word open-endedness, many still chose to use words/descriptions that are associated with experiments and investigations being either open-ended or not open-ended.

All of the students who were asked this question said that they would have preferred the same level of open-endedness in SCED 401. The following quotes were typical of how students felt about open-endedness:

> I think that there should be open-endedness but not too much, and not too little. There should be some type of balance in there. *[Researcher: "That reminds me of the three bears, not too soft, not too hard, but just right. Sort of in the middle."]*

> I think it was perfect *[SCED 401]*. Everything was like, it was a flow. The labs followed the lectures. We were able to have our own discussions with our own little groups. And it wasn't boring which is very important.

> You know that's a tough question for me because most of my prior classes didn't have any open-endedness. So I felt like there was quite a bit. Was it too much? I don't think it was too much. Could there have been more? Very possibly there could have been but, since I haven't been exposed to it, it's hard for me to say. I really, really like the fact that we did have as much open-endedness because I felt like I had a personal stake in it. I extended my own learning because I wanted to, and because I wanted to get as much as I could out of it.

The students in my intervention classes liked the level of open-endedness that the course offered them, and this did not adversely effect their attitude towards science. As mentioned earlier, my intervention classes had statistically significantly ($p<0.01$) more positive attitudes towards science compared to the nonintervention classes. On the attitude scale from the *Test of Science-Related Attitudes*, the average item mean was 4.38 for my classes and in comparison with the nonintervention classes, the effect size was 1.44 standard deviations. Surprisingly, despite many of these students' feelings of fear and anxiety over learning science, they still preferred less structured activities, divergent experiments and investigations, and choosing their own questions and procedures. They were not concerned that other students were collecting different data. Quotes in support of these statements follow:

> I also liked the Seabird Project where we were able to design our own researchable questions. *[In previous lab class]* …there wasn't any open-endedness with that one. It required very low thought. Pretty much my little sister could have done it.

> In my last biology class, we didn't really do any experimentation. I think the only investigating that we did was looking for the answers to questions that were in the book, or watching a slide show on a computer.

> I actually liked the way we did our open-endedness. I think it was a pretty good balance for us. I did different experiments than the other students…Dale did one and I did the other so we were all able as a group to collaboratively talk about it but we were still performing different things. I think it's good we weren't all doing the exact same test on borax. We weren't all testing sugar. We each tested a different mystery powder.

> I feel I did have the opportunity to pursue my own science interests. It gave me the opportunity to think first, instead of having the professor think for me. I feel it should stay at the same level because I feel I gained knowledge throughout this experience.

> I did have a project in Biology 200 where it was more work just looking into any topic. It seemed like they would allow you to pursue your own interests but it really wasn't because they were pre-selected. So we had to choose something that was pre-selected. It was kind of like, yeah, we'll let you guys choose but only from these, so you can't pursue your own interests. Everyone was trying to fight over the topic that seemed the most interesting.

> In going back to the open-ended question…. *[student was not asked this question, but volunteered this information]*. I think it was really good the way this class did it. At the beginning, they showed what was a researchable question and an observation. So it kind of first taught you the outline of an experiment. Then, at the end, you were able to do this open-ended *[Seabird]* Project and you already had all this knowledge that you can actually apply.

It is thought-provoking how several of the prospective elementary teachers mention the importance of balance. This is something I believe the SCED 401 instructors make a conscious effort to strive for. We avoid traditional 'canned' experiments and investigations, or what Colburn (2000) calls 'structured inquiry' in which the instructor provides hands-on problems to investigate, as well as the procedures and materials, but does not inform students of expected outcomes (p. 42). McRobbie and Fraser (1993) found that Open-Endedness had a significantly negative correlation with some scales on the *Test of Science-Related Attitudes*. The inappropriateness of too much open-endedness (the bed that is too hard) was alluded to in the following quotes:

> I would definitely say probably the same *[level of open-endedness]*. I think too much more would have left it open for everyone to go off on tangents. I think we really needed to see something this open because our other classes weren't. You learn more this way, rather than just having the content given to you.

> I think the amount that we had was just fine *[SCED 401]*. I think that, if there was a little more open-endedness, it would be a little scary for me because I'm not accustomed to that. I would have felt a little intimidated and very lost. But you made it just safe enough because we got more out of it. You gave us options and, at the same time, you didn't give us so many options that we would be totally off from what we were supposed to be doing. It was right in the middle, just what we needed.

We do not want students to feel lost or frustrated, and this is why SCED 401 instructors predominantly use 'guided inquiry' (Colburn, 2000) where the materials and topic or problem are provided, but the students devise their own procedures, and are encouraged to find multiple solutions to the same problem. I feel that it is imperative that instructors create a learning environment where students feel safe to take risks, and where they realize that it is acceptable not to have all the information given to them by the instructor. As good instructors know: "All learning involves risk. Yet, to take the leap of risk as a learner…there must not only be a safe and predictable learning environment, but also the learner must have a sense of entitlement, an audacity" (Erickson, 1998, p. 1157). However, when all these things happen, the results can go well beyond enjoyment of science lessons as one student said:

> Well, probably the same *[level of open-endedness in SCED 401]*. It helped my self-esteem.

In the following quotes, several of the prospective elementary teachers alluded to the nature of science when discussing open-endedness. These types of connections seem to indicate that students have reached deep understandings of the nature of science. The following two examples are illustrative of this:

> I feel we had a great deal of open-endedness. I think it helped us to understand why we do experiments in real science and the nature of science. I don't think we needed more per se, because without a certain amount of instruction we would have been lost. *[Researcher: "You mentioned open-endedness and related it to the nature of science. What do you mean by that?"]* Because in real science you don't have strict guidelines that you have to follow. Real scientists come up with questions that they want to answer and that's how information comes about. They research it and collect new data. That's the open-endedness of it. That's why we do it because that's how scientists do it.

> *[Previous laboratory class]* seemed to be a bit more canned—there wasn't that open-ended discovery where you were allowed to discover different things. When you read our seabird investigation, you'll understand it. We started off looking for one thing, found it, and found something totally different as well. Our entire class didn't do one thing. We happened to stumble upon it. So that's good.

The student in the first quote realized that science does not have a single scientific method and that science is based on empirical evidence. The second student discovered the beauty of serendipity. This is not one of the eight 'aspects' of the nature of science according to Lederman et al. (2002), but the importance of serendipity in scientific discoveries throughout history is undeniable. (The discovery of penicillin and the story of childbed fever in pregnant women in 17th Century Venetian hospitals are but two examples.) These kinds of quotes, that arise of their own accord through students' musings, are very valuable. In the next question, however, I explicitly ask students about the Antarctic Seabird Project and the nature of science.

6.3.4 Authenticity Leads to Understanding the Nature of Science

For the fifth interview question, I explained that Dr Hodum's and my purpose in having students use the Antarctic seabird data during the course was to help students to feel like scientists and to better understand how actual scientists do their work. I then asked them: "Can you give me an example during the Seabird Project when you did in fact feel like a scientist? Do you have any examples of an 'aha' moment during the Seabird Project when you understood something about scientific work that you had not previously realized?" The first part of the question tapped into the affective domain, while the second part was more of a cognitively-based question. Ultimately, however, the responses to these questions blended together, but provided good triangulation to data from the VNOS items described in Section 6.2.

Many students mentioned their line graphs. I got the sense that they had never made graphs of their own data in previous science classes, and were quite proud of their accomplishments in SCED 401 during the Seabird Project. Representative quotes are supplied below:

> That probably made me feel like a real scientist: just being able to communicate with group members and looking at our graph and discussing our different ideas and having to try to figure it out by myself, because we couldn't really come to a conclusion.
>
> *[Felt like a scientist]* While we were getting the numbers, we had to transfer them, and use just what we needed for mass growth. I've never done graphs like that, especially in science.
>
> I felt like a scientist when I organized my data and tried to graph it…all the data that Dr Hodum had collected.

I had wanted to make the Seabird Project an authentic inquiry experience in my intervention classes. By having a wildlife biologist post his actual data on the Antarctic seabird chick's growth (mass, culmen or beak, tarsus or leg, and wing), on my course's website, the students had the opportunity to use the same data that he used during his dissertation. The data were not 'watered down' in any way, and were bona fide measurements of between 40 and 50 individual chicks during each field season. Consequently, Dr Hodum supplied my classes with eight gigantic Excel spreadsheets (a spreadsheet showing four growth measurements for each of the four species of seabirds over two seasons). Lunetta (1998) explains that, when good laboratory activities are "supported by appropriate technologies such as microcomputer based labs and spreadsheets, well-conducted laboratory investigations can enable more effective science teaching and learning" (p. 260). Sifting through all the data and using only what they needed to answer their researchable question was a challenge for students that they seemed to appreciate, as exemplified in the following quotes:

> I felt like a bird specialist. I asked my boyfriend if he knew that there are petrels in Antarctica? I tried to teach other people, so I felt like a scientist. Also, I've never worked with that much data before with

> all those numbers. I mean, at first, it was really overwhelming but, when working with my partner, I felt like we were a team of scientists….how we were taking averages and just all the calculations.

> I remembered from that article *[from our course reading pack]* that it's not easy being a scientist, and that's how I felt because we had so much data, all those numbers. At the end, we didn't know why there was that drop in weight, so we had to investigate that. *[aha moment?]* One of the other girls at another table told us about the whole drop in weight and then she told us what the term was called *[pre-fledging mass recession]*, and we were like, oh, why didn't we find that out? *[Researcher: "That was like an 'aha' moment that you shared."]* Yeah, someone shared that with us. Wow, okay, that explains it. I get it now.

> I felt like a scientist analyzing data. I mean observations can be conducted in the lab, out of the lab, anywhere but, once you have your observations, you have to analyze them and find out what's useful and what's not.

> *[Felt like a scientist]* We were working with actual data that had been collected from the field versus an experiment that we set up in the classroom. We took his data from the real world and so there's more mistakes and there's more things that affect it like the weather.

> *[Felt like a scientist?]* We were working with real data and not made-up information that teachers usually get from a textbook.

These quotes could have just as easily been in response to the VNOS item "What is science?" Because the students were supplying a response to my interview question in the context of the Seabird Project, I feel that these responses, just like the project itself, were more authentic. These students clearly understood the empirical foundation for scientific knowledge. Awareness that nothing can be proven in science, in the absolute sense, was illustrated by a student who corrected herself in the following quote:

> *[Felt like a scientist?]* When we came to our conclusion and we had actually proven our researchable question, it was really refreshing to know that we were going out for something and trying to test something. We didn't actually prove it, we can't really prove something, but we had evidence to support our researchable question. So that made us feel kind of good. *[aha moment?]* When we were talking about the absolute size and the relative size of the two seabirds, we found it shocking that the smaller bird had a larger relative size for its wing.

Another student seemed to truly understand the rigors and hardship of scientific field work when she took the time at home to again view PowerPoint shows that Dr Hodum and I had produced on Antarctica and the general biology of the seabirds. Her awe can be sensed from the following quote:

> *[Aha moment?]* I remember looking through the PowerPoint presentations at home. It said something about him being there *[Antarctica]* for five months and I saw what they were living in. *[Researcher: "It was like a little orange igloo."]* Yes! I was like, oh, my gosh, all this work we have to use on these spreadsheets all came from that area with him living there, and just the conditions. I thought, we're kind of privileged to see all these data after he's worked there for so many months. I think it was realizing the scope of what scientists can do.

Lastly, the following three quotes illustrate additional understandings of the nature of science but, again, they go beyond Lederman's et al. (2002) list of target aspects. The first quote eloquently describes Occam's Razor (principle of parsimony—scientific phenomena should be explained in the most economical way possible; Cohen, Manion, & Morrison, 2000), the second quote conveys the realization that asking good questions in science is more important than always finding answers, and the third question broaches several aspects of the nature of science including the unity of science (a scale on the *Nature of Scientific Knowledge Survey*—NSKS that was not analyzed after the initial exploratory factor analysis):

> I had one. *[aha moment]* It was when we were making inferences on the culmen *[beak]* size of the two birds. We found out that the only difference was that one bird was bigger than the other. That was the moment when I thought, oh, this is what scientists do. Sometimes they make inferences that in the end they are what they thought they were originally. We didn't think it was going to be that simple. We tried to make it more complicated than it really was. *[Researcher: "So you never really realized that before about science, that sometimes the simplest explanation is the one you should go with?"]* I never had that option to think about it in science. It was always you do an experiment, and you get the answer, and that's it. You don't question the answer because that's what you're suppose to get.

> *[Aha moment]* That neither one of the culmens was bigger than the other one. I always felt that, when I do experiments, I need to find an answer. We kind of got to the end and saw that there was no difference. At first we were like, oh, we probably did something wrong. Then, when we went back, no really, this is what it is—we did everything right. Sometimes you do all the experiments and figure out there really is no difference.

> *[This student was explaining why her attitude had improved.]* This is the only science course I've taken that uses a process approach. It makes you understand what the nature of science is….*[Researcher: "You mentioned that it really showed you the nature of science. What do you mean by that?]* I really learned that there is no one experiment or one way to gain scientific knowledge. When I hear the word scientific, I know it has to be tested, it has to be repeated. I'm thinking back to Einstein and Newton and their tests, and how they had to keep repeating it. Ptolemy or Copernicus, at the time, were thought of as being radical. We have models. We have to back things up and constantly test your work. That's what nature of science is. Finding how it's all connected and related. Everything is interconnected and interwoven.

Overall, this interview question and the students' responses clearly illustrate that students recognized and appreciated the Seabird Project's authenticity. As Edelson (1998) explains, "Scientific practice is characterized by the attitudes of uncertainty and commitment. Any translation of scientific practice into educational settings must encourage these attitudes in order to provide authenticity" (p. 318).

6.3.5 Attitudes Towards Science

For my last interview question, I asked: "Would you say that your attitude towards science has stayed the same, improved, or declined as a result of taking this course? Can you describe what factors have contributed to this change?" The main purpose in asking this question was to support or refute my quantitative findings from using the scale called Enjoyment of Science Lessons from Fraser's (1981) *Test of Science-Related Attitudes*, and to test its construct validity. From analyzing associations between the learning environment and attitude, I found that Instructor Support accounted for the single best independent predictor of positive attitudes ($ß=0.87$, $p<0.01$). However, because I was playing dual roles of researcher and their instructor (i.e., I was a participant observer) (Atkinson & Hammersley, 1998), I felt that I was placing the students in a compromising situation, and this probably affected the responses that they gave me for this question.

All but one of the students said that their attitude had improved as a result of taking SCED 401. One student said that her attitude had stayed the same because she already had a positive attitude even before the course began. Other students reported that, in fact, they liked science before they began the course, but they still felt that their attitude had improved. Many students admitted that they even hated science prior to SCED 401.

As far as factors in SCED 401 that contributed to their improved attitudes towards science, the students mentioned an array of things. Similar to my first question about the biggest difference between their previous science laboratory class and SCED 401, students frequently disclosed the importance of having a science course designed with prospective elementary teachers in mind. The following quotes illustrate this well:

> In my last classes…there was a lot of important material there but you ask yourself, am I actually going to be teaching this to my students? In the science capstone course *[SCED 401]*, I feel that what we have learned here can be incorporated and integrated into my science classroom. It will help me to become successful in my teaching career.

> I would say definitely improved. I feel a lot more confident that when I have a classroom I'll be able to integrate science into it without using an extreme amount of time, or effort or money. I also think science helps kids across the board working on those processes. I think they are needed for all subjects. It can help them be better learners and students I think. *[Researcher: "What do you mean by across the board?"]* I think the processes of making inferences and using our prior knowledge. Those are the things they can use in reading comprehension or math or anything. I think science is a really good way to teach those processes and, at the same time, teach the science content they need.

Students also acknowledged the role of the instructor in creating a positive learning environment, as illustrated in the following two quotes:

> Definitely improved. I've never really had a good experience with science. Science was probably my least favorite subject because my teachers just weren't very enthusiastic about science.

> I think it has a lot to do with the activity that an instructor chooses because you can really make something interesting, or you can just make it hell. The instructor is the one that pretty much gets the classroom motivated.

Students often used quite strong words to describe their prior feelings about science as shown in the following quotes:

> *[attitude?]* Improved, major, major, major. I've hated science. I really didn't like it because I had such awful experiences. I've never gotten good grades no matter how hard I studied, no matter how hard I worked in the laboratory. It just does not click with me. I have never even gotten a 'B' in science. And after this course….I was able to see like a new light. I'm proud because I'm so excited. That's huge for me because I honestly had hated science. *[This student received a high 'B' in SCED 401.]*

> I think it's improved greatly. All the science classes that I've taken these past two years kind of pushed me away from science because we followed only one method and it didn't really interest me. After taking this course, it's really opened my eyes towards science the way I like.

> It's definitely improved. I hated science you know until now. Even so, I knew that I had liked it at some point. I liked it in elementary school and now I feel like I can go back to that and make science fun.

Lastly, it is usually a positive sign when people begin to voluntarily share their science learning experiences with friends and family:

> I would say it improved a little bit because I didn't really have a lot of positive experiences in my science classes before. I actually started thinking about some of the stuff we were doing afterwards. I guess I just started discussing it with family members and kids at my work. I went to my work, and I said "Guess what I had to do yesterday?" And the kids wanted to know what. I told them I had to dissect an owl pellet. They asked "What's that?" It's a thing that an owl spits up with the fur and the bones. We had to get all the bones out and I had my own little pellet. *[Researcher: "So it was the first*

> *time you actually talked about science with your friends and family?]* Yeah. We were talking about assignments outside of class. It was the first time I think I talked about something that I did in science.

6.4 Concept Maps on the Seabird Project and the Nature of Science

Every semester, I ask students on their final open-notebook, in-class examination to construct a concept map conveying how the Seabird Project has helped them to understand the nature of science. Concept maps are cognitive road maps and graphical representations of how a student understands, or does not understand, connections between related concepts (Novak, 1990; Novak & Gowin, 1984). Instructors can identify students who are suffering from a pattern of rote-mode learning (Novak, 1990), something that is inadvertently encouraged in many traditional science courses. Many science educators consider that concept maps are metacognitive tools with the potential to promote effective science laboratory learning (Lunetta, 1998; Novak, 1990; White & Gunstone, 1989, 1992). Throughout the semester, I provide mini-lectures on and examples of concept maps, and students practice making concept maps, individually and in groups, for other topics/activities in the course. Novak (1990) and Novak and Gowin (1984), in fact, feel that concept mapping facilitates cooperative learning. For the examination, I inform students that they must use at least 15 words or concepts on their map, along with ‘linking words’ on the lines that connect the words/concepts. In the past, I have discovered that linking words are very important for determining true understanding, and for identifying any lingering misconceptions or naïve beliefs.

Results typically vary from semester to semester, but quite often only about one-half of the students are able to synthesize the Seabird Project and the nature of science into one map. Synthesis is considered to be a higher order learning objective according to Bloom’s taxonomy (Bloom, Englehart, Furst, Hill, & Krathwohl, 1956) so this result is perhaps not surprising. We explicitly discuss and reflect upon Lederman et al.’s (2002) target aspects of the nature of science, but I also discuss other features, and explain how they all relate to the Seabird Project. Usually, however, only two or three features of the nature of science find their way on to maps. Some students appear confused over the distinction between the nature of science and the processes of science. Others seem to get caught up sharing all that they have learned about the Seabird Project, and forget to say anything about the nature of science (or do not understand the question).

I selected five students' concept maps from my intervention classes as another data source. The hand-drawn concept maps were then converted to an electronic format using the software program called 'Inspiration'. Four of the concept maps came from the fall 2002 semester. Two of the maps were considered 'good' and two were considered 'medium or average'. The fifth concept map, from the spring 2003 semester, was considered 'poor'. Although the content and construction was good in the latter concept map, I felt that there was little synthesis of the Seabird Project with the nature of science. These five concepts maps and my resulting analysis, provides yet another lens for viewing students' understandings of the nature of science, and at the same time, answers Part C of my fourth research question: *How does integrating real research data on Antarctic seabirds into a course affect prospective elementary teachers' understandings of the nature of science?*

One of the concept maps from fall 2002 that was considered 'good' is shown in Figure 6.2. The map indicates many references to the nature of science, and uses examples drawn from the Seabird Project. Of Lederman et al.'s (2002) list of eight target aspects, Nancy (pseudonym) included seven aspects. The only one which she omitted was the notion that science is based on both observation *and* inference. This is interesting because we do an in-class activity to clarify the difference between an observation and an inference (see Tricky Tracks activity, Lederman & Abd-El-Khalick, 1998, pp. 85-91), and then this distinction is reinforced throughout the course. Nancy did state that "observations are theory laden" (first aspect), but did not use the word 'inference' in her map. Although Nancy did not explicitly state the subjectivity of science, I still felt that she was implying subjectivity when she said that "observations are theory laden". Second, Nancy did say that "nature of science is tentative, for example, weather conditions," but this indicates Nancy does not really understand tentativeness. That is, "scientific knowledge is subject to change with new observations and with the reinterpretations of existing observations" (Schwartz et al., 2004, p. 613). I assume that Nancy was thinking of the fickle nature of Antarctic weather conditions, and its influence on data collection in the field. Third, Nancy states that "nature of science relies on observations or empirical evidence gathered by Dr Peter Hodum on seabirds in Antarctica". Here, I believe that she understands that "scientific knowledge is based on and/or derived from observations of the natural world" (Schwartz et al., 2004, p. 613).

Fourth, Nancy says that both "investigations or experiments can be creative". Fifth, she says that "nature of science can be political such as Dr Hodum's need for conservation funds". I felt that this was a good example of the 'sociocultural embeddedness' of science because she seemed to understand that Dr Hodum's work was dependent on sociocultural norms that value and support conservation issues. Sixth, Nancy clearly acknowledged that "hypothesis *[hypotheses]* do not become theories" and "theories do not become laws". Lastly, Nancy declared that "nature of science has no step-by-step scientific method such as hypothesis, then procedure, then observations/data, then conclusion". In addition, Nancy also included another important feature of the nature of science that was not included in Lederman et al.'s list. She clarified the distinction between a hypothesis and a prediction (something that we do discuss in the course), and even provided an example from the Seabird Project for each term. Overall, this is indeed a very good concept map because Nancy successfully synthesized her understanding of most of the nature of science aspects with the Seabird Project.

Figure 6.3 shows the second 'good' concept map from the fall of 2002. Amy (pseudonym) includes five out of the eight nature of science aspects, but also points out three important additional features. Amy alludes to the fact that (1) "Dr Peter Hodum being part of a researchable team shows that science is social" and that a researchable team consists of "like-minded investigators", (2) there is a difference between predictions and hypotheses, and (3) experiments have limitations and assumptions. Amy mentions an equal number of features about the nature of science as Nancy did, but also conveys some possible confusion in her case about why "observations are theory laden". Amy connected "theory laden" with "maneuverable thoughts" but did not include a linking word. It seems that she might have had some difficulties defining what is meant by 'observations are theory laden'. Amy also did not incorporate many examples from the Seabird Project into her concept map.

Figure 6.4 is a 'medium or average' concept map from the same semester. Claire only mentioned three out of the eight nature of science aspects (tentativeness, creativity, and empirical basis), although it is still a well-constructed concept map and shows more 'cross-links' between concepts than either Amy's or Nancy's concept maps. She also was the only one out of the five students who acknowledged that "scientific knowledge is not only generated by experiments". In class, I did inform them of this feature and used the well known primate studies by Diane Fossey and Jane Goodall as examples.

Jamie's concept map in Figure 6.5 also shows good cross-links but, unfortunately, she concentrates mainly on describing the Seabird Project. Although she does not mention any of the target nature of science aspects, Jamie still reveals fairly sophisticated understanding of how this scientific project was carried out both in the field and when she was working with the data in the classroom. Important features of scientific field work that Jamie included were the ideas that it is good to work in teams because one can learn about different perspectives, and that field work has limitations such as weather conditions, limited access to birds, and technology problems.

Lastly, Wendy's concept map in Figure 6.6 from spring 2003, has fairly good cross-links but shows a limited understanding of the nature of science. The only aspect that Wendy seems to understand is the empirical basis for science because she points out that observations can include both quantitative and qualitative data, and then gives examples from the Seabird Project. Although Wendy has illustrated that she can construct a concept map, unfortunately, she has not synthesized the nature of science with the Seabird Project.

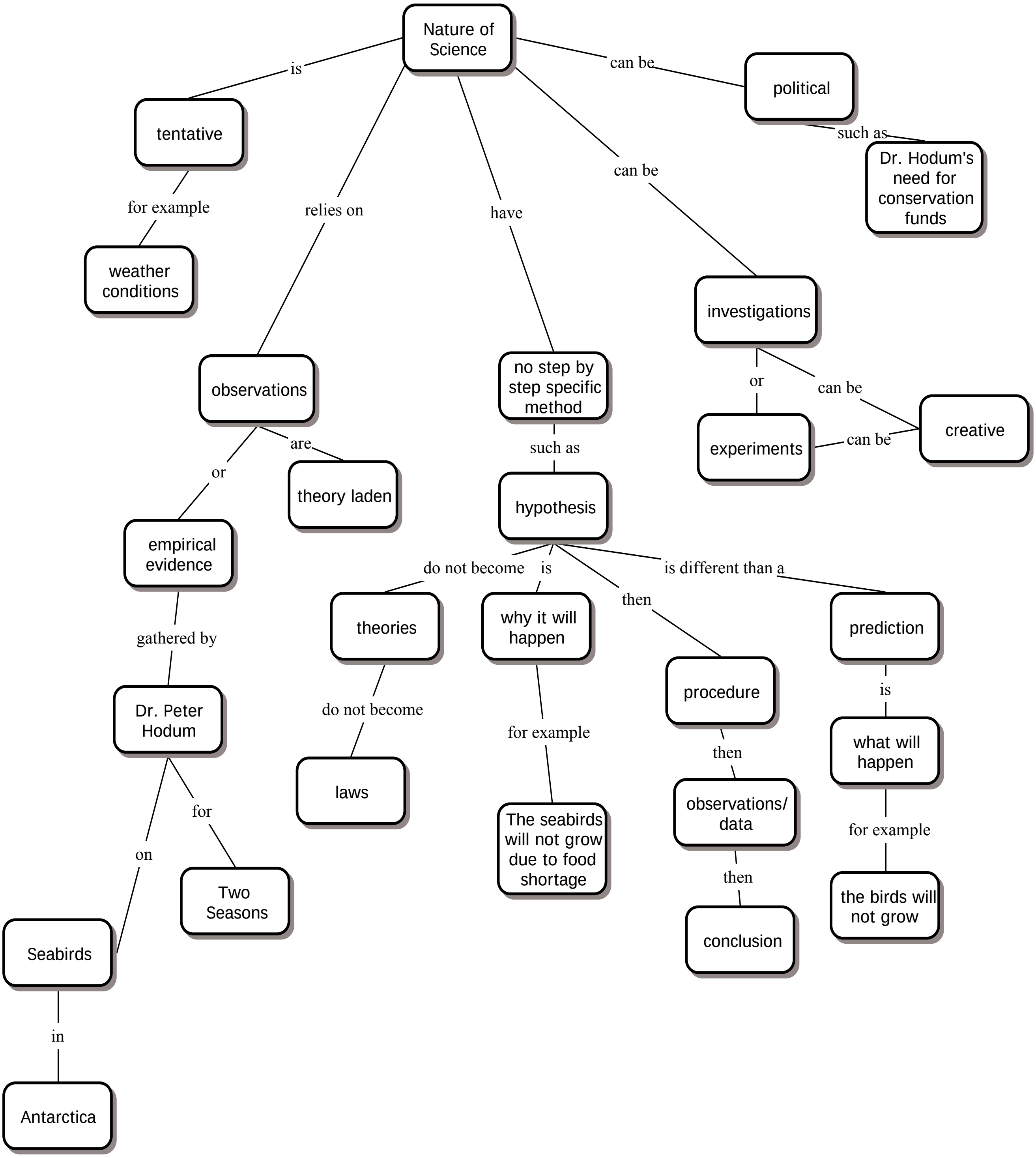

Figure 6.2 Nancy's 'good' concept map, fall 2002.

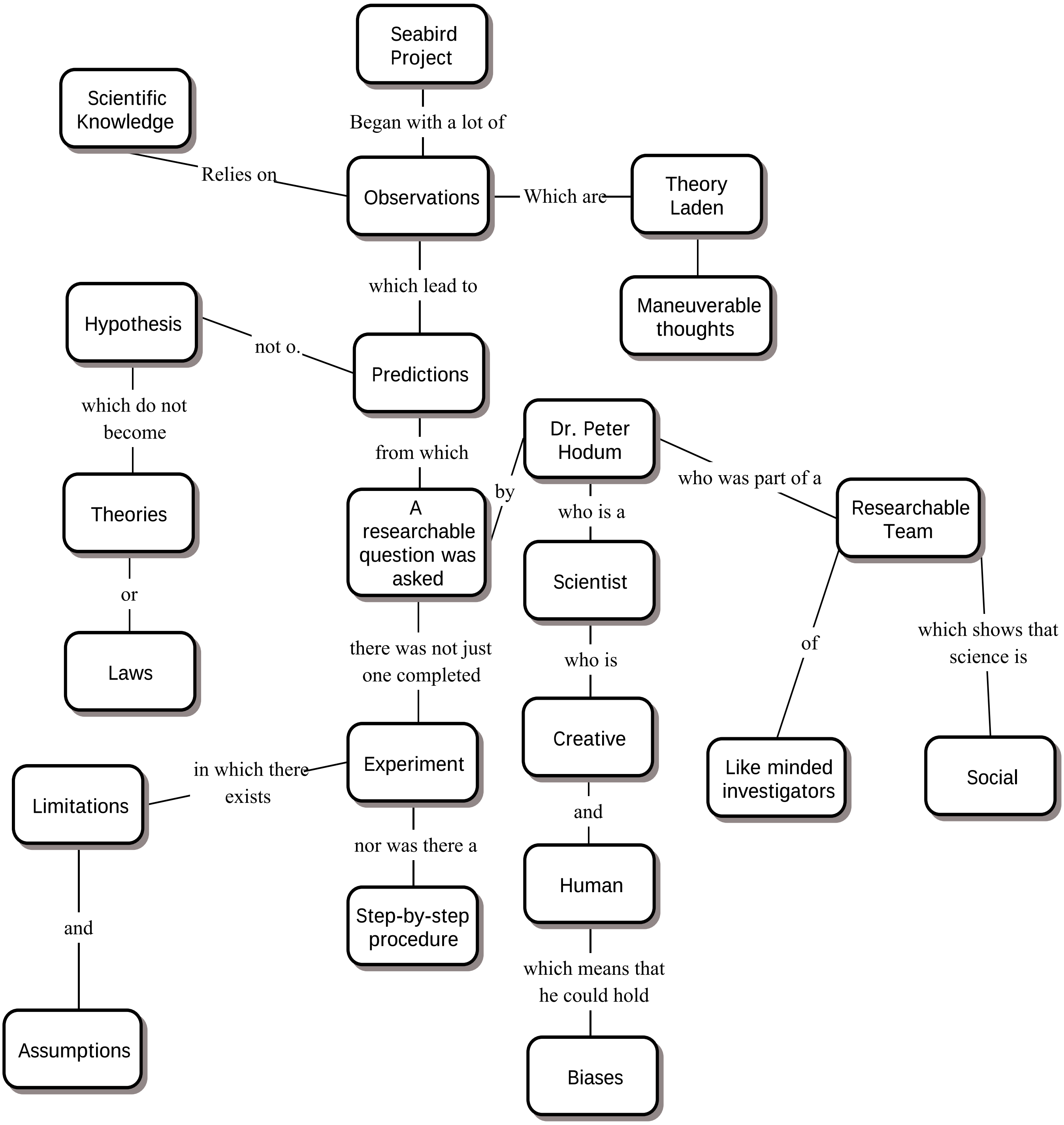

Figure 6.3. Amy's 'good' concept map, fall 2002.

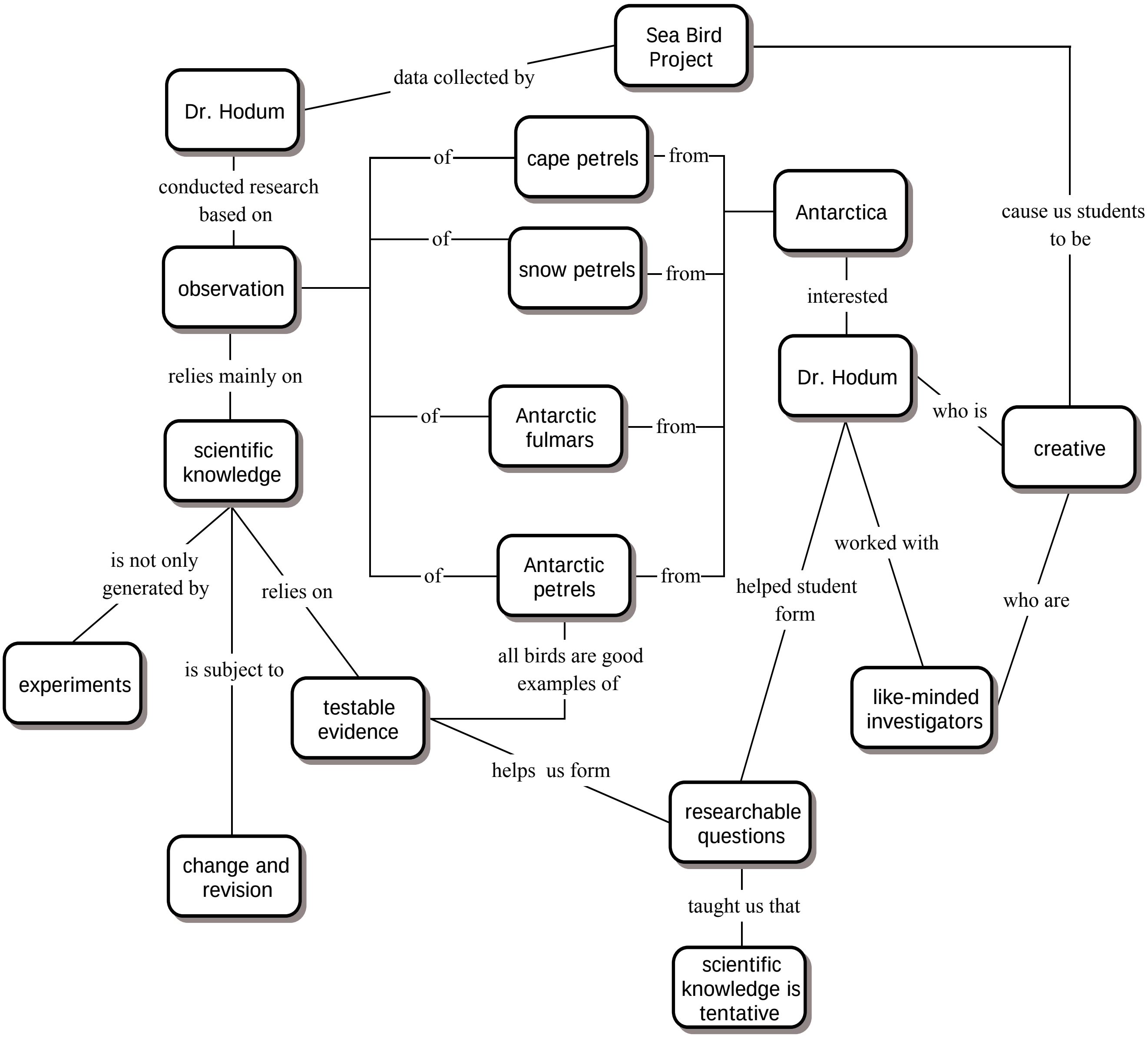

Figure 6.4. Claire's 'medium/average' concept map, fall 2002.

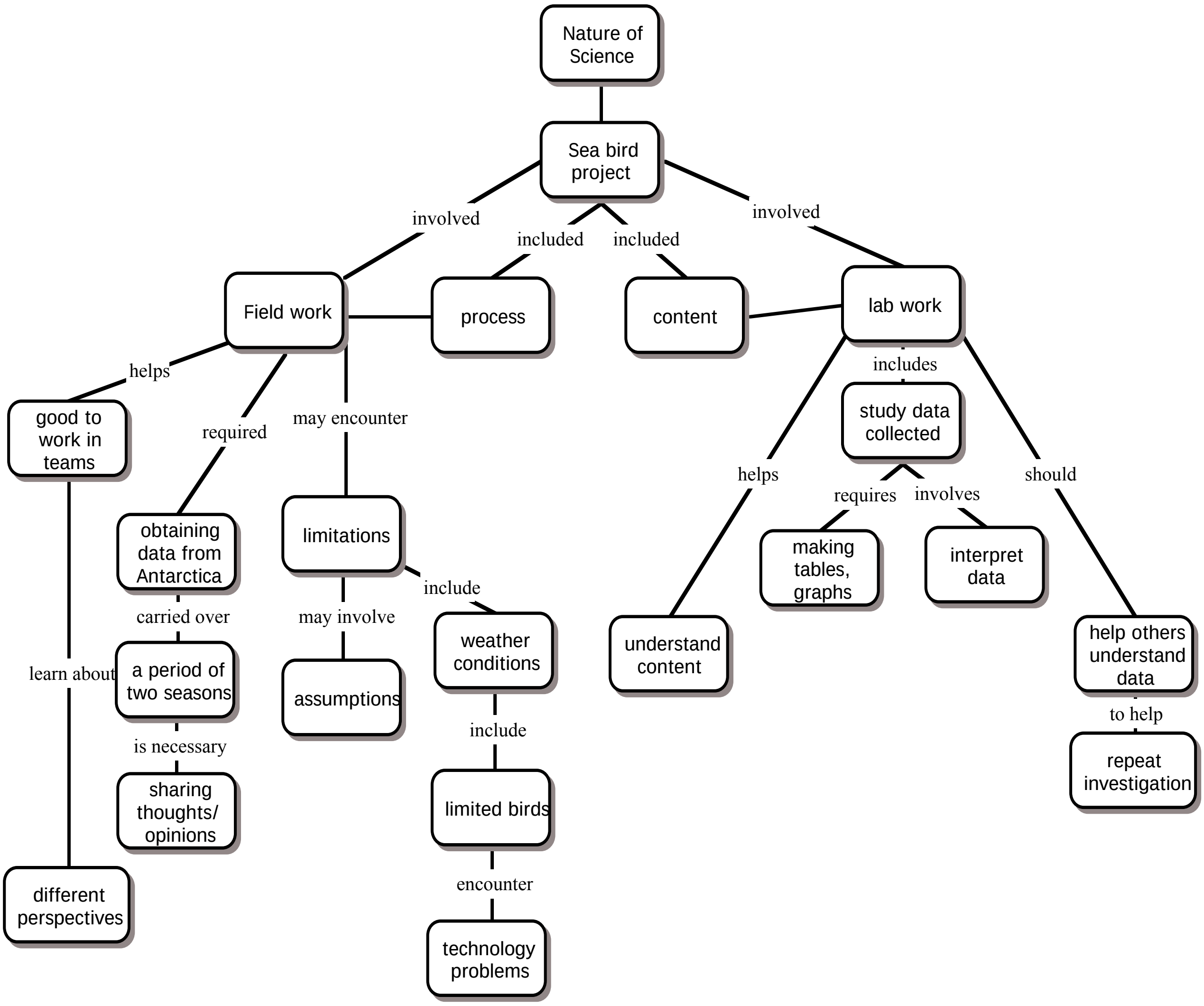

Figure 6.5. Jamie's 'medium/average' concept map, fall 2002.

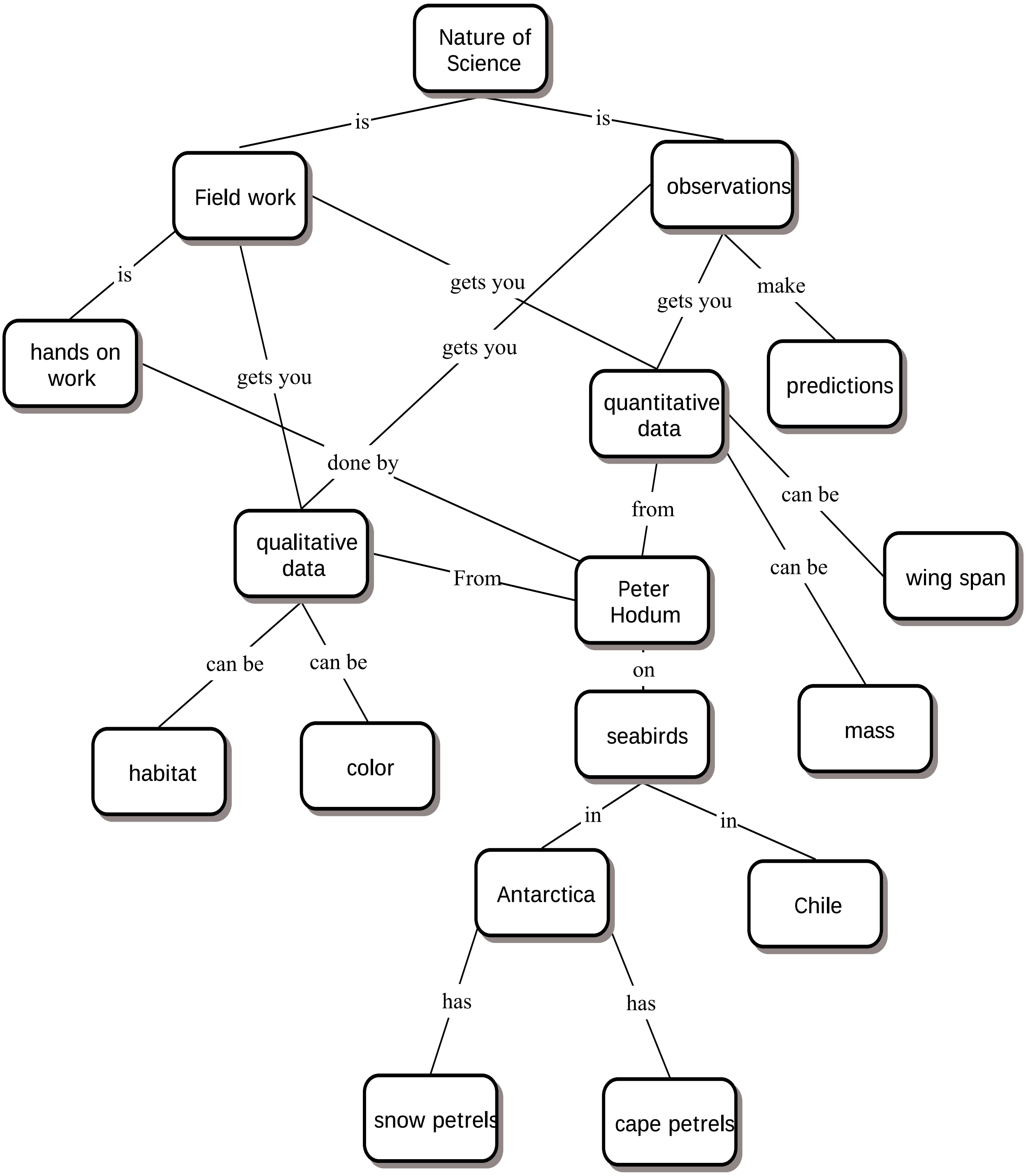

Figure 6.6. Wendy's 'poor' concept map, spring 2003.

6.5 Summary of Chapter

This chapter described the results of my qualitative data analyses gathered from three sources—*Views of Nature of Science* (VNOS) online survey, interviews with 35 students in the intervention classes, and five concept maps on the Seabird Project and nature of science. The VNOS data were used to determine whether students' understandings of the nature of science had improved, and to triangulate the results obtained from the quantitative instrument, *Nature of Scientific Knowledge Survey* (NSKS) (Rubba & Anderson, 1978). The concept maps were used to shed some light on the possible effects of integrating real research data on Antarctic seabirds into the intervention classes of SCED 401, and on understandings of the nature of science. The interviews covered aspects of the students' perceptions of the learning environment and attitudes towards science, as well as understandings of the nature of science. The qualitative data analyses provided an examination of patterns in the forest, as well as a closer look at individual trees.

The NSKS results revealed statistically significant differences on two out of the four scales that were used to compare understandings before SCED 401 began (pretest) with understandings at the end of the course (posttest). Pre-posttest changes had an effect size of 2.05 standard deviations for Creative, and an effect size of 1.67 standard deviations for Unified. When the intervention classes were compared with the nonintervention classes, only the scale of Creative was statistically significant ($p<0.01$) with an effect size of 1.03 standard deviations. The three questions that were analyzed from the VNOS did not correspond with scales on the NSKS as well as I had hoped. The one exception was that both instruments attempted to assess understanding of the role of creativity in scientific work and among scientists. The VNOS revealed that, although prospective elementary teachers seemed to have a better-than-average understanding (compared to Lederman et al.'s, 2002, participants) on the pretest that creativity is used in all three stages of an investigation—planning and design, data collection, and after data collection (32.2% said this)—they still made a noticeable improvement on the posttest (45.2%) on this aspect of the nature of science. The second VNOS question "What is an experiment?" corresponds vaguely with the scale of 'Testable' on the NSKS. Whereas no statistically significant differences were found between pretest and posttest scores for Testable on the NSKS, the VNOS revealed considerable improvement in the numbers of prospective elementary teachers who could describe the qualities of a good, traditional experiment (15% on the pretest versus 61% on the posttest).

The third VNOS question about theories and laws presented the most challenge, and very little improvement on the posttest was noted. On the pretest, 46.9% believed that theories have not been proven yet, while laws have been proven, but this belief was only reduced to 30.6% on the posttest. Although the VNOS did reveal improvements in the prospective elementary teachers' understandings of the nature of science, there is still a great deal of room for additional improvement. No comparisons were made between VNOS responses in the intervention classes compared to the nonintervention classes because there was a large discrepancy between the number of my students who responded compared to the number of students who responded from the nonintervention classes. Naturally, I had a large stake in the results because the study was also my thesis, and so I had a greater percentage of my students answering the questions online.

The interviews with 35 prospective elementary teachers in the fall 2003 nonintervention classes provided a vibrant montage of science teaching and learning. The interview items did not address each of the survey's six learning environment scales individually but, nevertheless, aspects of all six scales did manifest themselves in the prospective teachers' responses. The interviews strongly supported the survey's finding that the biggest difference between students' previous science laboratory class and SCED 401 was the degree of Open-Endedness (effect size of 6.74 standard deviations). All six scales on the survey revealed statistically significant differences ($p<0.01$) between previous laboratory science classes and SCED 401, with most ideas contained in each scale being mentioned by the prospective teachers. The one exception in which a scale was not consistently alluded to was that of Material Environment, although the design and arrangement of desks/tables did get mentioned. I was unable to conclusively determine from the interviews why my intervention classes had statistically significantly lower Student Cohesiveness. However, I feel confident that part of the reason must lie with the fact that I require students to work in groups of two or three to write up two of the larger assignments/reports, and this caused a lot of stress and anxiety.

With regard to attitudes towards science, all but one student said that her attitude had improved. I believe that, if prospective elementary teachers from the nonintervention classes were also interviewed, the same result would have been found. However, without having done this (i.e., interview students in the nonintervention classes), I cannot provide any evidence from the interviews to explain why the intervention classes had a statistically significantly ($p<0.01$) higher average item mean for Enjoyment of Science Lessons (effect size of 1.44 standard deviations) from the *Test of Science-Related Attitudes,* despite the significantly lower Student Cohesiveness.

Lastly, the five concept maps on the Seabird Project and the nature of science served as a novel complement to the quantitative data, and to the commonly-used approach of interviewing. They were representative of good, average, and poor concept maps that conveyed skill at map construction but, more importantly, meaningful understanding of how and why the Seabird Project was used to learn about the nature of science. Without producing exact counts of good, average, and poor concept maps in all six intervention classes, however, interpretation of the implications of the concept maps must be conservative. Nonetheless, they provided a window into the prospective elementary teachers' metacognitive world and their understandings of the nature of science as it related to the Seabird Project. Overall, the use of both quantitative and qualitative methods in my study clearly illustrates the power of the idea of grain sizes.

Chapter 7

DISCUSSION AND CONCLUSIONS

7.1 Introduction

Learning environments research has had a long and illustrious history for close to 35 years. Very few studies, however, have involved teacher preparation programs. My study is distinct in that it investigated perceptions of the psychosocial learning environment, attitudes towards science, and understandings of nature of science among female prospective elementary teachers enrolled in an innovative science course at a large urban university in Southern California. The study is also the first to build a bridge between classroom learning environment and the student outcome of understanding the nature of science.

This chapter provides an overview of the thesis in Section 7.2. I provide a summary of the introductory chapter, the two chapters that reviewed literature relating to learning environments and nature of science, and the research methods chapter. Quantitative and qualitative results are summarized in Section 7.3. Distinctive contributions of my study are discussed in Section 7.4, including its significance and implications. Limitations are discussed in Section 7.5, while Section 7.6 makes recommendations and suggestions for further research. Lastly, Section 7.7 provides a summary and concluding remarks.

7.2 Overview of the Thesis

Chapter 1 began by stating that many prospective elementary teachers dislike science and even could have a ‘phobia’ of the subject itself. These negative feelings often originate from their previous experiences in elementary and secondary schools and in undergraduate science courses in college and university. The course investigated in my study, *A Process Approach to Science—SCED 401*, is a required course for a Liberal Studies degree at California State University, Long Beach, and was designed specifically for prospective elementary teachers.

During the four semesters of 2002 and 2003 when data were collected from 525 female prospective elementary teachers, I taught six of the 27 classes (22%). All of my classes received an ‘intervention’, which I describe as *guided authentic scientific inquiry*. The intervention consisted of providing students with a database, for an experimental design project, on four species of Antarctic seabirds and their growth rates. The wildlife biologist who collected the data also participated in my classes on a part-time basis.

My study’s purpose was to describe and evaluate the impact of SCED 401 on prospective elementary teachers’ perceptions of the learning environment, attitudes towards science, and understandings of nature of science. I compared students’ perceptions of the learning environment and attitudes during their previous science laboratory course with perceptions and attitudes during SCED 401. I also investigated students’ understandings of nature of science prior to SCED 401 (i.e., pretest), based on their overall science education experience (not just their previous laboratory class). Comparisons were then made after SCED 401 (i.e., posttest). Another purpose was to describe the impact of using the Antarctic seabird data on my students’ learning environment perceptions, attitudes, and nature of science understandings compared to students in the nonintervention classes. Lastly, I explored associations between the learning environment and the outcomes of attitudes and understanding nature of science, building on considerable prior learning environment research.

My study encompassed two large and distinct research fields—learning environments and the nature of science. Because the two research areas, however, have been predominantly unassociated, I divided my review of related literature into two separate chapters. Chapter 2 reviewed literature relating to learning environments, while Chapter 3 dealt with the nature of science studies.

Chapter 2 was divided into five main sections—Section 2.1: Background to the Learning Environments Field; Section 2.2: Instruments That Assess Learning Environments; Section 2.3: Science Laboratory Environment Inventory; Section 2.4: What Is Happening In this Class?; and Section 2.5: Attitudes Towards Science and Their Link with the Learning Environment. Background information covered learning environments’ genesis in the social sciences with the work of Lewin (1936) and Murray (1938), pioneer psychologists who first analyzed psychosocial environments. Their work led to the development of the first instruments used in school settings beginning in the 1960s, namely, the *Learning Environment Inventory* (Walberg & Anderson, 1968), *Classroom Environment Scale* (Moos, 1974), *My Class Inventory* (Fisher & Fraser, 1981), *Individualized Classroom Environment Questionnaire* (Fraser, 1990; Rentoul & Fraser, 1979), and *College and University Classroom Environment Inventory* (Fraser & Treagust, 1986). Throughout the 1990s, at least six more instruments were developed to assess unique instructional settings and purposes such as laboratories, teacher-student interactions, constructivist learning environments, and web-based and distance education milieus. In contemporary research, *What Is Happening In this Class?* (Fraser et al., 1996) is frequently used because it combines scales from past questionnaires with contemporary dimensions to bring parsimony to the field of learning environments (Aldridge et al., 1999).

Chapter 2 also discussed important developments and considerations with learning environment instruments, as well as the general lines of past research conducted. For example, the distinction between private beta press (view individuals have of their own environment) and consensual beta press (view that members of a class hold about the environment) is an important consideration during the design of a study and subsequent analysis. Various forms must be chosen depending on the researcher's purpose such as a preferred or actual form, the choice of a short or long form for some questionnaires, a personal or class form and, recently, whether the form will be in paper-and-pencil, hard-copy format, or placed on the Internet. Four types of past research include (1) associations between learning environment and student outcomes such as attitudes or cognitive achievement, (2) use of environment dimensions as criterion variables in the evaluation of reforms, interventions, or new teaching strategies, (3) investigations of whether students achieve better when in their preferred environment, and (4) teachers' action research aimed at improving their classroom learning environment (Fraser, 1986). Another hallmark of the field is that there are many cross-national studies that have compared learning environments in several countries (Aldridge & Fraser, 2000).

A large section of Chapter 3 reviewed in detail studies that used the *Science Laboratory Environment Inventory* and *What Is Happening In this Class?* For my study, I used scales from both of these instruments to produce a six-scale modified questionnaire for use with my sample of prospective elementary teachers. Lastly, attitudes towards science and its link with the learning environment were discussed. One scale called Enjoyment of Science Lessons, from the *Test of Science-Related Attitudes* (Fraser, 1981), was used in my study.

In Chapter 3, I defined and described the term ‘nature of science’. A simple definition is that nature of science encompasses the field of epistemology, which focuses on how scientific knowledge is generated and in the character of science itself. Current reform documents such as the National Science Education Standards (NRC, 1996) promote learning and understanding the history and nature of science for all K–16 students, and stress that nature of science is integral to achieving scientific literacy.

Chapter 3 described the development and validation of the two nature of science instruments I used in my study—*Nature of Scientific Knowledge Survey,* NSKS, and the *Views of Nature Of Science,* VNOS. Three issues related to teaching and learning about nature of science were mentioned. These included a comparison of explicit-reflective versus implicit approaches to inquiry instruction, contextualized versus decontextualized formats and, finally, a discussion of the recent trend to use authentic scientific inquiry to teach and learn about nature of science. Studies relevant to these issues were briefly described at this point in the chapter.

The review of nature of science studies were separated into two time periods—those studies between 1950 and 1990 (Table 3.2) and those from 1991 to the present (Table 3.3). Most of the emphasis, however, was on studies dealing with prospective, preservice, or inservice elementary teachers, as this group aligns with my study’s sample. Between 1950 and 1990, only two out of 19 studies (10%) involved elementary teachers. During the following 13.5 years, 20 out of 55 studies (36%) involved elementary teachers. During these 13.5 years, only one study combined quantitative and qualitative methods in investigating elementary teachers’ understandings of the nature of science in the context of a science course.

Chapter 4 described the quantitative and qualitative methods that I used in my study. Blending both theoretical perspectives into a single study is recommended by learning environment researchers (Fraser & Tobin, 1991; Tobin & Fraser, 1998) because it capitalizes on the ideas of *grain sizes*—the use of different-sized samples for different research questions varying in extensiveness and intensiveness (Fraser, 1999), triangulation, and complementarity. I validated both the modified learning environment questionnaire and the

Nature of Scientific Knowledge Survey using factor analyses. Internal consistency reliability and discriminant validity were also determined. The ability to differentiate between classrooms (ANOVA results) was determined for the learning environment scales.

Descriptive statistics (average item mean, effect size) were used to investigate differences between students' previous laboratory course and SCED 401 with regards to learning environment and attitudes, and differences in understandings of nature of science before and after SCED 401. *T*-tests for paired samples indicated the statistical significance of any differences. Because of the possibility of a Type I error associated with multiple *t*-tests, a modified Bonferroni procedure was used. Differences between the intervention and nonintervention classes were determined in a similar fashion using *t*-tests for independent samples.

Associations between the learning environment and the student outcomes of attitudes towards science and understanding of nature of science were determined using simple correlation and multiple regression analyses, using two units of analysis (the student and the class mean).

Views of Nature Of Science, VNOS, was used to generate qualitative data. The VNOS includes 10 open-ended response items developed around eight 'aspects' or tenets of nature of science that are considered relevant to and attainable by K–16 learners. I used four of the 10 items, as they were for triangulation and complementary purposes only, and not used as the primary method of data collection. For each VNOS item, an analytic inductive/recursive process was used to identify themes in the students' responses. An analytical chart or typology (Erickson, 1998) then summarized the frequency and type of perspectives and beliefs represented.

In addition to the questionnaires, I also conducted semi-structured interviews with a subsample of students (*n*=35) from my intervention classes. The questions mainly involved comparisons between students' previous laboratory class and SCED 401 in terms of cooperative learning groups, open-endedness, experiments and investigations, and their attitudes towards science. One question also was asked about the Antarctic Seabird Project. Audiotaped interviews were transcribed, and an analytic induction process was used to identify themes.

My last data source included five concept maps that illustrated and synthesized students' understandings of the nature of science as they related to the Antarctic Seabird Project. My analysis consisted of rating each concept map as good, average or poor, based on how many nature of science aspects or other features were mentioned, along with examples from the project. The last section of Chapter 4 discussed some limitations of my method.

7.3 Major Findings of the Study

The major findings of my study are summarized in the two primary sections that follow. Section 7.3.1 summarizes the quantitative results discussed in Chapter 5, while Section 7.3.2 summarizes the qualitative results from Chapter 6.

7.3.1 Summary of Quantitative Results

7.3.1.1 Validity and Reliability of Learning Environment Scales, Attitude Scale and Nature of Scientific Knowledge Survey

Principal components factor analyses confirmed that the large majority of the learning environment items belonged to their *a priori* scale. Forty-three out of 46 items had factor loadings above 0.40 on their *a priori* scale and no other scale for previous laboratory classes and/or for SCED 401. This result indicates that combining scales from two different learning environment instruments can still produce a valid instrument for use with prospective elementary teachers. Principal components factor analyses for the NSKS, using pretest and posttest scores, indicated a weaker factor structure. Therefore, rather than using a factor loading of 0.40 as the cut-off point, items with factor loadings less than 0.30 were omitted from further analyses. Only four of the six scales on the NSKS had a sufficient number of items with values over 0.30.

Cronbach alpha reliability coefficients were high for all learning environment scales and for Enjoyment of Science Lessons. Using the class mean as the unit of analysis, Cronbach alpha coefficients ranged from 0.69 to 0.98 for the learning environment scales. For Enjoyment of Science Lessons, Cronbach alpha coefficients were 0.96 for the previous laboratory class and 0.98 for SCED 401, using the class mean as the unit of analysis.

Cronbach alpha coefficients for the four scales on the NSKS were fairly high for both the pretest and posttest. Using the class mean as the unit of analysis, values ranged from 0.74 to 0.87 for the pretest, and from 0.59 to 0.91 for the posttest. These results indicate that, by removing 21 of the 48 items, the internal consistency reliability of the remaining four NSKS scales improved considerably.

Discriminant validity of the learning environment scales was acceptable, although the scales do overlap somewhat. Values of the mean correlation of a scale with the other scales ranged from 0.17 to 0.54, using the class mean as the unit of analysis. Discriminant validity of the four NSKS scales was fairly good. For the pretest, discriminant validity values ranged from 0.19 to 0.30, and for the posttest, values ranged from 0.05 to 0.15, using the class mean as the unit of analysis. This was the first time discriminant validity had been determined for the NSKS.

For SCED 401, all six learning environment scales differentiated significantly between classrooms ($p<0.05$). Eta^2 values ranged from 0.08 to 0.23. For previous laboratory classes, only two scales significantly ($p<0.05$) differentiated between classrooms.

7.3.1.2 Differences Between Previous Laboratory Classes and SCED 401 in Learning Environment and Attitudes, and Pretest-Posttest Differences for the Nature of Science

There were statistically significant differences for all six learning environment scales and for Enjoyment of Science Lessons when previous laboratory classes and SCED 401 were compared. Understandings of nature of science improved after SCED 401 as well, but increases were not as impressive as for the learning environment and attitude scales. Effect sizes were unusual for all learning environment scales, with values ranging from 1.51 to 6.74 (for Open-Endedness) standard deviations. The effect size for Enjoyment of Science Lessons was 2.98 standard deviations. The effect size was small for two scales on the NSKS, and large for the other two scales (e.g., 2.05 for Creative).

For previous laboratory classes, the average item mean had the low value of 2.30 (i.e., Open-Endedness occurred ‘seldom’), a result that replicates the large cross-national study that used the *Science Laboratory Environment Inventory* with over 5,000 university and high school students in six countries (Fraser et al., 1995). It is interesting to note that, in the cross-national study, students preferred to have a more favorable learning environment with regard to all scales on the SLEI, except Open-Endedness. Students who rarely experience open-ended, inquiry-based laboratory environments can feel a certain level of anxiety during an unusual instructional approach, and this could have contributed to the finding in the cross-national study. Although my study did not compare actual and preferred learning environments, students rated the actual level of Open-Endedness in SCED 401 with an average item mean of 3.85. With the Enjoyment of Science Lessons scale receiving an average item mean of 4.06, it seems probable that the level of inquiry (a blend of *guided inquiry* and *open inquiry* in all classes, and *guided inquiry* and *authentic scientific inquiry* in the intervention classes) provided a comfortable but cognitively-engaging learning environment.

Results of the *t*-tests for paired samples comparing the two groups were statistically significant ($p<0.01$) for all scales assessing the learning environment and for the attitude scale, even with applying the modified Bonferroni procedure. For the NSKS, changes on two scales (Creative and Unified) were statistically significant using the modified Bonferroni procedure ($p<0.01$).

7.3.1.3 Differences Between Intervention and Nonintervention Classes in Learning Environment, Attitudes and the Nature of Science

For the intervention classes, two learning environment scales and the attitude scale had higher average item means than for the nonintervention classes. However, between-group differences were statistically significant ($p<0.05$) only for the attitude scale. Three scales had lower average item means for the intervention classes compared to the nonintervention classes, with differences for one scale (Student Cohesiveness) being statistically significant ($p<0.05$). Effect sizes ranged from 0.00 to 1.53 standard deviations, using the class mean as the unit of analysis. These results indicate that providing students with the Antarctic Seabird database for their experimental design project, did *not* lead to an appreciable improvement in students' perceptions of the learning environment. This is probably due to a 'ceiling effect' that has been previously documented (Dorman, 2003). Nevertheless, students enjoyed their science lessons more in the intervention classes (i.e., a statistically significant difference was found; $p<0.01$), but it is unclear whether this was directly a result of using the Antarctic seabird data and having the wildlife biologist participate in the class. Including an interview question that simply asked "What did you enjoy the most in the course?" would have shed some light on this issue.

For the NSKS, two scales had average item means that were higher for the intervention classes, with differences being statistically significant for Creative ($p<0.05$). Two scales had lower scores compared to the nonintervention classes, but neither were significant. Effect sizes ranged from 0.42 to 1.03 standard deviations, using the class mean as the unit of analysis. These results again indicate that providing real research data on Antarctic seabird growth rates for students to use during their experimental design project does not dramatically improve their understandings of the nature of science as measured by the NSKS, with the exception of improved understandings that creativity and imagination are necessary in scientific work. However, it should be noted that two of the scales from the NSKS (Amoral and Unified) are not considered contemporary descriptions of nature of science. They were not observed on a consensus list of objectives derived from eleven international science education documents (see Figure 3.1), and they are not included in the VNOS's eight aspects describing the nature of science. Real research data on Antarctic seabird growth rates was used primarily to create an *authentic scientific inquiry* investigation. Realizing that scientific knowledge cannot be judged as good or bad (Amoral) or that the various specialized sciences contribute to a network of theories, laws, and concepts (Unified), were not natural consequences of the Seabird Project.

7.3.1.4 Associations Between Learning Environment and the Outcomes of Attitudes and the Nature of Science

Results of the simple correlation analyses indicated that a statistically significant ($p<0.01$) association exists between Enjoyment of Science Lessons and all six learning environment scales, using the individual as the unit of analysis. Using the class mean as the unit of analysis, two scales were significantly correlated with Enjoyment of Science Lessons. Results of the multiple correlation analyses indicated a statistically significant multiple correlation between the learning environment and Enjoyment of Science Lessons, for both units of analysis ($R=0.66$ for the individual; $R=0.82$ for the class mean). Standardized regression weights indicated that Instructor Support had the greatest independent influence ($ß=0.51$; $p<0.01$) on Enjoyment of Science Lessons, using the individual as the unit of analysis. Using the class mean as the unit of analysis, Instructor Support was again the greatest independent predictor of enjoyment (ß=0.87; $p<0.01$). These results suggest that supportive, friendly and encouraging instructors, who take a personal interest in students' lives, could well have an strong effect on students' enjoyment of the course.

Results of the simple correlation analyses for the NSKS revealed only relatively weak correlations with learning environment, although associations were statistically significant for several scales, using the individual as the unit of analysis. A statistically significant multiple correlation was found between the learning environment and the Creative, Testable, and Unified scales, using the individual as the unit of analysis. Standardized regression coefficients indicated that Open-Endedness was a significant independent predictor of the Creative scale, while Cooperation, Open-Endedness and Material Environment were all significant independent predictors of the Testable scale. Material Environment was a significant independent predictor of the Unified scale. All significant regression coefficients were positive, confirming a positive link between a favorable classroom environment and the student outcome of understanding the nature of science.

7.3.2 Summary of Qualitative Results

Qualitative findings expanded and complemented my quantitative results. A summary of my findings are provided in the following three sections. Section 7.3.2.1 summarizes findings from the VNOS, Section 7.3.2.2 summarizes the interviews, and Section 7.3.2.3 summarizes my analysis of the concept maps.

7.3.2.1 Views of Nature Of Science (VNOS) Online Survey

During the spring of 2003, 115 matches were made between pretest and posttest responses for a question asking at which stages (planning and design, data collection, after data collection) of a scientific investigation scientists use their creativity and imagination. According to the developers of the VNOS, most people believe creativity is needed only during the planning and design stage. My analysis showed that 26.9% of the SCED 401 students responded in this fashion on the pretest, and this was reduced to 21.7% on the posttest. A total of 32.2% believed scientists use creativity during all stages on the pretest, and this increased to 45.2% on the posttest. Although the 13% increase is a positive sign, this still leaves over half of the prospective elementary teachers with a lack of understanding of this aspect of the nature of science, even after undertaking SCED 401.

The *Nature of Scientific Knowledge Survey* showed a statistically significant (p<0.01) difference between before and after SCED 401 for the scale of Creative. In addition, differences between intervention and nonintervention classes are statistically significant (p<0.05) on the Creative scale. Students in the intervention classes seemed to have a better understanding of the role of creativity and imagination in scientific work (effect size was 1.03 standard deviations). In my analysis of the VNOS responses, however, I did not distinguish between responses based on the students' instructor and, therefore, cannot cross-check this finding.

During the fall of 2003, two questions were asked—*What is an experiment?* and a second question about any differences between a theory and a law. From the 98 pretest-posttest matches that were made, five themes emerged from the analysis of the first question, ranging from simple 'naïve' definitions to a description of a good traditional experiment, representing an 'informed' response. On the pretest, 15% gave an informed response, but this increased to 60.5% on the posttest. The *Nature of Scientific Knowledge Survey's* scale, Testable, aligns somewhat with this question. However, a statistically significant difference between before and after SCED 401 was not found for this scale. Here is a good example of where the construct validity of the Testable scale could be called into question.

The question regarding theories and laws seemed to be the most challenging for students. Relatively little change was observed between pretest and posttest responses. Only 9.2% of the students provided a correct definition on the posttest (up from zero). The misconception that "Theories haven't been proven yet, while laws have been proven" was very prevalent in both pretest and posttest responses.

7.3.2.2 Interviews With Students in the Intervention Classes

Interviews were conducted with 35 students in my intervention classes (22.2% of one semester's enrollment or 7% of the total sample size). Five themes were identified that embodied the prospective elementary teachers' responses.

The first theme, 'The Abyss Between Previous Laboratory Courses and SCED 401' describes how the majority of students said that the biggest difference between their previous laboratory class and SCED 401 was related to open-endedness. This finding strongly confirms the learning environment questionnaire results that indicated a statistically significant difference ($p<0.01$) for the scale of Open-Endedness, and suggests that the scale has good construct validity.

The second theme, 'Student Grouping≠Student Cohesion or Cooperation describes how students explained that previous laboratory classes did have groups, but that they were rarely cohesive or cooperative. Grouping seemed to be a way to split up the laboratory work in order to get it done as quickly as possible. An unusual finding was that my intervention classes had statistically significantly less Student Cohesiveness ($p<0.05$) compared to the nonintervention classes, yet they enjoyed their science lessons more than the nonintervention classes ($p<0.01$). Upon personal reflection, I realized that I was the only instructor who required students to write up reports in groups of two or three. In light of the current educational climate of increasing emphasis on high GPAs and a change to California's teacher credentialing process requiring candidates to pass a standardized examination in multiple subject areas before they can seek employment, I need to reconsider this approach.

All students indicated that they would have preferred the same level of open-endedness in the class (rather than more or less), and hence my third theme was 'Like the Three Bears Story—It Was Just Right'. Despite many of the students' feelings of fear and anxiety over learning science, and negative past experiences in science laboratory classes, they still preferred less structured activities, divergent experiments and investigations, and to choose their own questions and procedures. Student responses alluded to the importance of balance—again, guided inquiry seems to provide this.

'Authenticity Leads to Understanding Nature of Science' emerged as a prominent theme when students discussed the Antarctic Seabird Project. Providing the students with a database of real information on the petrel chicks' growth rates, to use during their experimental design project seemed to simulate authentic scientific reasoning at various stages of the project. Although the quantitative data did not directly provide insights on how the Antarctic Seabird Project affected students' perceptions of the learning environment, attitudes towards science, or understandings of the nature of science as measured by the questionnaires, the interview data clearly indicated that there was a positive impact on these three factors.

The fifth theme, ‘Attitudes Towards Science’, includes responses that support the finding from the Enjoyment of Science Lessons scale of a statistically significant difference between previous laboratory classes and SCED 401 ($p<0.01$). This suggests that the scale has strong construct validity, a finding that replicates considerable past research (Fraser & Butts, 1982). Whether these positive attitudes are resilient is unclear, particularly when prospective elementary teachers become practicing teachers in their own classrooms. Many factors would certainly affect their attitudes after SCED 401, such as the learning environment of their science methods course, the university where they earn a teaching credential, the amount of time in between SCED 401 and beginning a credential program, and the value placed on science education by the school, other teachers, and administrators.

In analyzing associations between the learning environment and attitudes, Instructor Support accounted for the single greatest predictor of positive attitudes ($ß=0.87$, $p<0.01$). During the interviews, however, students only occasionally mentioned instructor support as being a factor that contributed to their improved attitudes. This is likely to be due to the fact that I was playing the dual roles of the researcher and their instructor during the interviews and, therefore, they might have been embarrassed about being forthright. Overall, students’ responses suggested the importance of having science courses designed specifically for prospective elementary teachers. Prospective teachers want and appreciate a sprinkling of pedagogical content knowledge in a course.

7.3.2.3 Concept Maps From Students in the Intervention Classes

The five concept maps provided another lens into students’ understandings of the nature of science, and how they were able (or not able) to synthesize those understandings with the Antarctic Seabird Project. However, because not all students’ concept maps were collected and analyzed, it is difficult to make conclusions from my analysis of only five concept maps. Nevertheless, having taught SCED 401 19 times to date, I can say that students have difficulty synthesizing aspects of the nature of science with the Seabird Project. This is probably not surprising considering ‘synthesis’ is a higher-order thinking skill according to

Bloom's taxonomy (Bloom et al., 1956). The five maps represented a cross-section of 'good', 'average' and 'poor' representations that I usually see every semester.

7.4 Distinctive Contributions, Significance and Implications of Study

My study has contributions to offer in three areas: (1) learning environments research, (2) elementary teacher preparation programs, and (3) nature of science research. My study is the first to adopt a learning environments framework in evaluating a science course specifically designed for prospective elementary teachers at the university level. Fisher and Fraser (1991) recommended incorporating learning environment ideas into teacher education over a decade ago, but this is one area of the learning environments field that has remained largely untapped. The learning environment questionnaire modified for use with my sample indicated good validity and reliability, and can be used with confidence in future studies involving prospective or preservice teachers in a laboratory class.

My study provides insights into 'traditional' laboratory classes that many undergraduates (and not just prospective elementary teachers) must take, and on a hybrid laboratory/seminar class that was dramatically different from previous laboratory classes. *A Process Approach to Science*—SCED 401 is the only nontraditional laboratory class that students take prior to applying to a teacher credential program. The course gives students a different perspective on science teaching and learning. My study showed that there was a statistically significant difference between their previous laboratory classes and SCED 401 for all learning environment scales, with the greatest difference being the level of open-endedness. As found in many earlier studies, previous laboratory classes had low levels of open-endedness (Fraser et al., 1992a; 1995; Henderson et al., 2000; McRobbie & Fraser, 1993; Waldrip & Wong, 1996; Wong & Fraser, 1996). If instructors of the previous laboratory classes (usually one of the prerequisite courses) were informed of these results, some could decide to make improvements to their courses' learning environment, which in turn, would benefit future students.

SCED 401 is the only course during their undergraduate science education that provides prospective elementary teachers experience with guided, open, and authentic inquiry, supportive instructors who are not concerned with rote memorization, and collaboration and group cooperation. Simply having a small class size (25—30 students) at the university level seems to help to create a positive learning environment. Students do science in SCED 401—free from textbooks, worksheets, and preset or 'cookbook' laboratory investigations. This kind of learning environment gives students the autonomy to problem-solve, take risks, exercise their creativity, and have an enjoyable science learning experience.

A statistically significant difference was found between previous laboratory classes and SCED 401 for the Enjoyment of Science Lessons scale. My study has shown that, when students perceive the actual level of open-endedness as fairly high (average item mean for Open-Endedness was 3.85 for SCED 401), they still enjoy the course as well (average item mean for Enjoyment of Science Lessons was 4.06). Simple correlation and multiple regression analyses also indicated a positive association between Open-Endedness and Enjoyment of Science Lessons (r=0.36 and ß=0.12; p<0.01), using the individual as the unit of analysis.

My study adds to the richness of multi-method studies conducted over the past five years (Aldridge & Fraser, 2000; Aldridge et al., 2002; Aldridge et al., 1999; Hine & Fraser, 2000; Hofstein et al., 2001; Ntuli et al., 2003; Pickett & Fraser, 2004; Raaflaub & Fraser, 2003; Sinclair & Fraser, 2002; Wallace et al., 2002; Zandvliet & Fraser, 2004). Other studies have used interviews to verify the construct validity of learning environment scales and to create interpretive stories and narrative commentaries. But, in addition to interviews, I also used an open-ended response instrument and concept maps to investigate associations between the learning environment and understandings of the nature of science. The interviews, however, contributed most to my study's learning environment *bricolage* and to uncovering differences in the learning environment of students' previous laboratory classes and SCED 401, as expressed in the prospective elementary teachers' own voices. In addition, the interviews supported the strong construct validity of the scale, Enjoyment of Science Lessons, from the *Test of Science-Related Attitudes* (Fraser, 1981).

In terms of elementary teacher preparation programs, my study has implications for both the future teaching practice of elementary teachers and the learning of their future students. If beginning elementary teachers harbor a phobia or dislike of science, these beliefs will be passed on to their students. If beginning elementary teachers do not have a positive experience during any of their undergraduate science courses, coupled with pressures to improve standardized test scores in mathematics and reading, science is likely to be the first subject discontinued by teachers. My study suggests that, with a positive experience in a laboratory course designed specifically for future teachers, elementary teachers are more likely to teach science to their own students and in the same open-ended, divergent style that they experienced during SCED 401. SCED 401 can be a model for other colleges and universities with elementary teacher preparation programs that do not have such a course.

In the nature of science field, my study appears to be the third study (Bright & Yore, 2002; Meichtry, 1992) that has conducted a factor analysis on the *Nature of Scientific Knowledge Survey* (Rubba & Anderson, 1978). The results of my factor analysis support the two earlier studies in that not all scales are factorially strong. When 'faulty' items are removed, however, internal reliability and discriminant validity of the remaining scales are quite good. Although *Views of Nature Of Science* (Lederman et al., 2002) was not used exactly as the developers had intended, my study does show that the VNOS can be modified, used for triangulation purposes, and complement and expand quantitative data—none of which has been undertaken in previous nature of science studies using the VNOS. My study suggests that the VNOS has potential for use in multi-level studies involving large sample sizes.

My study builds upon Bianchini and Colburn's (2000) study of SCED 401 in which they investigated the implicit use of inquiry to teach the nature of science by analyzing videotaped lessons. By using the *Nature of Scientific Knowledge Survey* and the *Views of Nature Of Science,* I was able to identify specific aspects of the nature of science that were being addressed in the course. Bianchini and Colburn stressed the instructor's crucial role in initiating reflective whole-class and small-group discussions about the nature of science. Through simple correlation analysis, I found that Instructor Support does indeed have a positive association with three aspects of nature of science—Creative, Unified, and Testable, for both the individual and class mean as the units of analysis.

My study makes a contribution to science education research, in general, because it was the first study to build a bridge between learning environments and understandings of the nature of science. Lederman and Druger (1985) and Lederman and Zeidler (1987) attempted to identify classroom variables that influence improved understandings of the nature of science in secondary biology classrooms, but they did not use any of the learning environment instruments available during the 1980s (e.g., *Classroom Environment Scale*, *Individualized*

Classroom Environment Questionnaire). My study's findings suggest that a favorable learning environment can have a positive impact on an area of cognitive achievement not previously investigated (i.e., understandings of the nature of science), yet supports prior research that also found a positive relationship between the learning environment and the student outcome of achievement (Fisher et al., 1997; Fraser, Haertel, Walberg, & Haertel, 1981; Henderson et al., 2000; McRobbie & Fraser, 1993).

7.5 Limitations and Constraints

In interpreting the findings of my study, there are several limitations that should be mentioned. First, a major limitation with this study is internal validity and reliability. I was the researcher-instructor who taught all of the intervention classes. One disadvantage of being a researcher-instructor is that it is difficult to 'refrain from teaching'. I could have inadvertently over-emphasized aspects of the nature of science compared to the other instructors, for example. It is possible that the observed differences between the intervention and nonintervention classes had nothing to do with the Antarctic Seabird database and the wildlife biologist's visits to my class. Therefore, interpretation of data must be scrutinized because being a participant-observer colors the subjective nature of the interpretive process (Anderson, 1998). Data can be subject to biasing influences such as 'demand characteristics' (subjects respond in accordance with their perceptions of the expectations of the researcher) (Hersen & Barlow, 1976), and we know that people typically provide socially-acceptable responses which might not be valid (Anderson, 1998). Also, on the first day of classes, students completed the learning environment and attitude questionnaire based on their previous laboratory class—a 'retrospective' approach that might have affected the quality of responses.

Second, in terms of external validity, it is probable that my findings could be generalized to many other undergraduate laboratory science courses and to prospective and preservice elementary teachers at numerous other universities in the United States. It would be inappropriate, however, to generalize the findings to other populations of students (e.g., males) at the tertiary level, graduate science courses or to other countries. Using only female students in my study created a limitation in that my findings can only be generalized to courses and/or programs that are also dominated by female students. At the same time, the

SLEI and WIHIC, from which I extracted scales, have been validated and used with university students in several countries outside of the United States (Fraser,a et al., 1992a; Fraser & Giddings, 1995; Fraser & Griffiths, 1992; Fraser & Wilkinson, 1993; Kim & Kim, 1995; Margianti et al., 2002). Therefore, it might be possible to tentatively generalize the findings outside of the United States to include tertiary female students with similar sample characteristics and to comparable undergraduate laboratory science courses.

Third, a complete assessment of prospective elementary teachers' attitudes towards science was constrained because I used only one scale from the *Test of Science-Related Attitudes*. In addition to the Enjoyment of Science Lessons scale, the TOSRA has six other scales. As discussed in the following section, it is recommended that a more thorough analysis of prospective elementary teachers' attitudes towards science be completed by using a wider range of attitude scales from the TOSRA or other attitude questionnaires.

Fourth, the present study encountered time constraints in the collection of data. Although all SCED 401 instructors were very supportive and cooperative when I visited their classes to administer the survey, I tried to take no more than 30 to 40 minutes of their instructional time. Considering that the total questionnaire had 102 items, this might not have been a sufficient amount of time.

7.6 Recommendations for Future Research

This section makes six recommendations for future research in both the learning environments and nature of science fields. Several recommendations could be combined in a single study.

To build upon my study involving prospective elementary teachers, an untapped population in learning environments research, I recommend additional multi-method studies at other universities in the United States as well as in other countries and, if possible, to choose courses that contain a sufficiently higher proportion of male students to permit meaningful investigation of gender issues. Although my sample size of 525 was adequate, studies with even larger sample sizes are recommended. In a similar spirit as in prior learning environments research, it would be interesting to conduct cross-national comparisons of laboratory science classes at the tertiary level.

A person-environment fit perspective could be applied to an assessment of the learning environment in SCED 401. In my study, I assessed only the *actual* perceptions because comparisons were made with previous laboratory classes. Comparing prospective elementary teachers' preferred and actual perceptions would provide valuable data that does not presently exist for this population.

A more comprehensive assessment of attitudes towards science should be conducted in the SCED 401 classes and in other undergraduate science courses at California State University, Long Beach. Using the scale of Enjoyment of Science Lessons provides only a narrow view of this important affective domain. A wider variety of scales from the TOSRA (Fraser, 1981) or other attitude instruments could be used to shed further light on the impact of innovative science courses such as SCED 401.

A follow-up study on our prospective elementary teachers who have taken SCED 401 would be worthwhile. Some students would be taking methods course, either at California State University, Long Beach, or at another institution. Others would be student teaching, teaching in their own classrooms, or pursuing other endeavors. Do students remember that the learning environment of SCED 401 was markedly different from their previous laboratory classes? For those that are teaching, has SCED 401 affected how they teach science to their own students? What kind of a science learning environment have they created in their classroom and, how does it compare to the one that they experienced in SCED 401? These interesting questions are waiting to be answered.

If the instructors of the prerequisite science courses were informed of the results of this study with regard to the learning environment, some might wish to conduct a small action-research study to improve their course in a similar vein as Yarrow et al.'s (1997) study. I would recommend focusing on Instructor Support and Open-Endedness to begin with. My study found that the biggest difference between students' previous laboratory classes and SCED 401 was Open-Endedness, but that Instructor Support contributed the most to students' Enjoyment of Science Lessons.

Large-scale evaluative studies continue to be highly regarded in educational governance and politics. Because a call for a new up-to-date standardized instrument assessing understandings of the nature of science exists in the science education community, it behooves someone to take the initiative to develop and validate a new instrument. I recommend modifying the NSKS scales of Creative, Developmental, and Testable, along with converting aspects covered by the VNOS into a five-option frequency response format. A valid instrument that provides a numerical score for individual scales or aspects of the nature of science seems to be needed.

7.7 Chapter Summary and Concluding Remarks

This study validated a modified learning environment instrument with a population of 525 female prospective elementary teachers. Findings indicate that there are large and statistically significant differences between prospective elementary teachers' perceptions of the learning environment and attitudes of their previous science laboratory course compared to SCED 401. Positive gains were revealed on all six learning environment scales and the Enjoyment of Science Lessons scale with the largest difference being the level of Open-Endedness. Qualitative data in the form of interviews support the construct validity of several learning environment scales, as well as the attitude scale, and serve to complement, expand, and add depth to the questionnaire data.

Differences between prospective elementary teachers' understandings of the nature of science before SCED 401 compared to after the course were not as dramatic as the learning environment and attitude differences between SCED 401 and previous laboratory courses. However, for two scales from the *Nature of Scientific Knowledge Survey,* there were positive and statistically significant differences (Creative and Unified) during the course. Qualitative data, generated from the *Views of Nature Of Science* and concept maps, augmented additional aspects of the nature of science beyond the four NSKS scales, and provided insights into specific notions that students find challenging to comprehend or to synthesize with inquiry-based activities.

Statistically significant positive correlations were found between all six learning environments scales and Enjoyment of Science Lessons. The combined influence of the learning environment scales indicates a statistically significant multiple correlation coefficient of 0.82, using the class mean as the unit of analysis. Standardized regression weights indicated that Instructor Support had the largest independent influence (ß=0.87). Multiple correlations were statistically significant for three scales of the *Nature of Scientific Knowledge Survey*, at the individual level of analysis. All significant regression coefficients were positive, confirming a positive link between a favorable classroom environment and the student outcome of understanding the nature of science.

The effect of providing prospective elementary teachers with a database on Antarctic Seabird growth rates, creating a guided authentic inquiry project (i.e., the intervention), needs further investigation. Quantitative data indicated very little difference between intervention and nonintervention classes with regard to the learning environment, while a significant difference was found for Enjoyment of Science Lessons and for the *Nature of Scientific Knowledge Survey* scale of Creative. Interviews revealed that students had indeed learned a great deal about scientific data interpretation and analysis, and about the subtle 'habits of mind' (Raizen & Michelsohn, 1994) that scientists possess.

The results from this study have implications for science laboratory instructors and elementary science teacher educators who wish to achieve more positive laboratory classroom environments, more enjoyable science lessons, or to improve understandings of the nature of science. Elementary teacher preparation programs seem to be constantly 'under reform'. We know we must improve and possibly redesign 'traditional' science courses for prospective elementary teachers—but how? My study provides data generated from a large sample of university students on how to make improvements. Rather than focusing on testing or adding more courses, my study shows that paying attention to affective aspects of education (especially providing instructor support) can improve attitudes towards science—an excellent place to start in any reform initiative. Within the field of learning environments research, my research makes a distinctive contribution because it is the first study to investigate laboratory classroom environments at the university level with prospective elementary teachers. This is a very important population to involve in classroom learning environment studies because of the long-term influence and 'ripple effect' that a positive science learning experience in a teacher preparation program can have for children in future elementary classrooms. If we want children to be creative, to be problem-solvers, and to enjoy science throughout their education and daily life, their science teachers must not be afraid ‘to teach with the textbook shut’. As Carl Jung the Swiss psychiatrist said:

> *One looks back with appreciation to the brilliant teachers, but with gratitude to those who touched our human feelings. The curriculum is so much necessary raw material, but warmth is the vital element for the growing plant and for the soul of the child.* *(Kelly-Gangi & Patterson, 2002, p. 83)*

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APPENDIX A

Previous Laboratory Course:
Science Learning Environment and Attitude Survey

Directions for Students

We would like you to complete this questionnaire based on your **PREVIOUS science laboratory course** that you took at CalState-Long Beach or elsewhere. Place a check mark on the appropriate line below indicating your last science laboratory course. (Note: If you took two laboratory classes simultaneously, please select one of them for the purposes of this survey.) If your last science laboratory course was taken elsewhere, please indicate the course name and location (school where enrolled) below.

___ Physical Science 112
___ Biology 200
___ Geology 102 with 104
___ Geology 106
___ Chemistry 105
___ Other science lab course at CSULB called ____
___ Other science lab course at another school
Name of course: ______________________School Name: ___________________________

This questionnaire contains statements about practices that may have taken place during your last science laboratory course. You will be asked how often each practice took place. There are no 'right' or 'wrong' answers. Your memories and/or opinions are what is wanted. Read each statement carefully, and think about how well each statement describes what your **PREVIOUS science laboratory course** was like for you.

Draw a circle around

1	if the practice took place **Almost Never**
2	if the practice took place **Seldom**
3	if the practice took place **Sometimes**
4	if the practice took place **Often**
5	if the practice took place **Almost Always**

Be sure to give an answer for all questions. If you change your mind about an answer, just cross it out and circle another. Some statements in this questionnaire are fairly similar to other statements. Don't worry about this. Surveys are constructed using similar questions multiple times. Simply give your opinion about all statements based on the science laboratory class you chose above.

Background Information

Current SCED 401 INSTRUCTOR'S NAME (circle one): Colburn Kisiel Martin Plumlee Saylor Writer

Your new CSULB STUDENT ID #: _____ ____ ____ ____ _____ _____ _____ _____ _____

Your gender (circle one): Male Female

Your Age: _____________

Year in college (circle one): Freshman Sophomore Junior Senior

If you are a Liberal Studies Major, what is your concentration? _________________________________

	IN MY PREVIOUS LABORATORY CLASS…				
Student Cohesiveness	**Almost Never**	**Seldom**	**Some times**	**Often**	**Almost Always**
1. I made friends among other students.	1	2	3	4	5
2. I knew other students.	1	2	3	4	5
3. I was friendly to other students.	1	2	3	4	5
4. Other students were my friends.	1	2	3	4	5
5. I worked well with other students.	1	2	3	4	5
6. I helped other students who were having trouble with their work.	1	2	3	4	5
7. Students liked me.	1	2	3	4	5
8. I got help from other students.	1	2	3	4	5
Instructor Support	**Almost Never**	**Seldom**	**Some times**	**Often**	**Almost Always**
9. The instructor took a personal interest in me.	1	2	3	4	5
10. The instructor went out of his/her way to help me.	1	2	3	4	5
11. The instructor considered my feelings.	1	2	3	4	5
12. The instructor helped me when I had trouble with the work.	1	2	3	4	5
13. The instructor talked with me.	1	2	3	4	5
14. The instructor was interested in my problems.	1	2	3	4	5
15. The instructor moved about the class to talk with me.	1	2	3	4	5
16. The instructor’s questions helped me to understand.	1	2	3	4	5
Investigation	**Almost Never**	**Seldom**	**Some times**	**Often**	**Almost Always**
17. I carried out investigations to test my ideas.	1	2	3	4	5
18. I was asked to think about the evidence for statements.	1	2	3	4	5
19. I carried out investigations to answer questions coming from discussions.	1	2	3	4	5
20. I explained the meaning of statements, diagrams and graphs.	1	2	3	4	5
21. I carried out investigations to answer questions that puzzled me.	1	2	3	4	5
22. I carried out investigations to answer the instructor’s questions.	1	2	3	4	5
23. I found out answers to questions by doing investigations.	1	2	3	4	5
24. I solved problems by using information obtained from my own investigations.	1	2	3	4	5

	IN MY PREVIOUS LABORATORY CLASS…				
Cooperation	**Almost Never**	**Seldom**	**Some times**	**Often**	**Almost Always**
25. I cooperated with other students when doing assignment work.	1	2	3	4	5
26. I shared my books and resources with other students when doing assignments.	1	2	3	4	5
27. When I worked in groups, there was teamwork.	1	2	3	4	5
28. I worked with other students on projects.	1	2	3	4	5
29. I learned from other students.	1	2	3	4	5
30. I worked with other students.	1	2	3	4	5
31. I cooperated with other students on class activities.	1	2	3	4	5
32. Students worked with me to achieve class goals.	1	2	3	4	5
Open-Endedness	**Almost Never**	**Seldom**	**Some times**	**Often**	**Almost Always**
33. There was opportunity for me to pursue my own science interests.	1	2	3	4	5
34. I was required to design my own experiments to solve a given problem.	1	2	3	4	5
35. Other students collected different data than I did for the same problem.	1	2	3	4	5
36. I was allowed to go beyond the regular laboratory exercises and do some experimenting of my own.	1	2	3	4	5
37. I did different experiments than some of the other students.	1	2	3	4	5
38. The instructor decided the best way for me to carry out the laboratory experiments.	1	2	3	4	5
39. I decided the best way to proceed during laboratory experiments.	1	2	3	4	5
Material Environment	**Almost Never**	**Seldom**	**Some times**	**Often**	**Almost Always**
40. I found that the laboratory was crowded when I was doing experiments.	1	2	3	4	5
41. The equipment and materials that I needed for laboratory activities were readily available.	1	2	3	4	5
42. I was ashamed of the appearance of the laboratory.	1	2	3	4	5
43. The laboratory equipment that I used was in poor working order.	1	2	3	4	5
44. I found that the laboratory was just the right temperature to work in.	1	2	3	4	5
45. The laboratory was an attractive place for me to work in.	1	2	3	4	5
46. My laboratory had enough room for individual or group work.	1	2	3	4	5

	IN MY PREVIOUS LABORATORY CLASS…				
Enjoyment of Science Lessons	**Almost Never**	**Seldom**	**Some times**	**Often**	**Almost Always**
47. I looked forward to lessons.	1	2	3	4	5
48. Lessons in the class were fun.	1	2	3	4	5
<u>49</u>. I disliked lessons in the class.	1	2	3	4	5
<u>50</u>. Lessons in the class bored me.	1	2	3	4	5
51. The class was one of the most interesting college classes.	1	2	3	4	5
52. I enjoyed lessons in the class.	1	2	3	4	5
<u>53</u>. Lessons in the class were a waste of time.	1	2	3	4	5
54. The lessons made me interested in science.	1	2	3	4	5

Nature of Scientific Knowledge Survey

The following questionnaire contains 48 statements about the nature of scientific knowledge. Read each statement carefully, and ***based on your prior overall science education experience (NOT focusing on just one course)***, indicate your level of agreement or disagreement with each statement. Some statements in this questionnaire are fairly similar to other statements. Don't worry about this. Simply give your opinion about all statements.

Draw a circle around

1 if you **strongly disagree** with the statement
2 if you **disagree** with the statement
3 if you are **neutral** about the statement
4 if you **agree** with the statement
5 if you **strongly agree** with the statement

	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
1. The applications of scientific knowledge can be judged good or bad; but the knowledge itself cannot.	1	2	3	4	5
<u>2</u>. Scientific laws, theories, and concepts do **<u>not</u>** express creativity.	1	2	3	4	5
3. We accept scientific knowledge even though it may contain error.	1	2	3	4	5
4. Scientific knowledge is stated as simply as possible.	1	2	3	4	5
<u>5</u>. Scientific knowledge need **<u>not</u>** be capable of experimental test.	1	2	3	4	5
6. The laws, theories, and concepts in biology, chemistry, and physics are related.	1	2	3	4	5

	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
7. It is incorrect to judge a piece of scientific knowledge as being good or bad.	1	2	3	4	5
8. Scientific knowledge expresses the creativity of scientists.	1	2	3	4	5
9. The truth of scientific knowledge is beyond doubt.	1	2	3	4	5
10. If two scientific theories explain a scientist's observations equally well, the simpler theory is chosen.	1	2	3	4	5
11. Consistency among test results is **not** a requirement for the acceptance of scientific knowledge.	1	2	3	4	5
12. The laws, theories, and concepts in biology, chemistry, and physics are **not** linked.	1	2	3	4	5
	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
13. Certain pieces of scientific knowledge are good and others are bad.	1	2	3	4	5
14. Scientific laws, theories, and concepts express creativity.	1	2	3	4	5
15. Today's scientific laws, theories, and concepts may have to be changed in the face of new evidence.	1	2	3	4	5
16. Scientific laws, theories, and concepts are **not** stated as simply as possible.	1	2	3	4	5
17. A piece of scientific knowledge will be accepted if the evidence can be obtained by other investigators working under similar conditions.	1	2	3	4	5
18. The laws, theories, and concepts of biology, chemistry, and physics are **not** related.	1	2	3	4	5
	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
19. Even if the applications of a scientific theory are judged to be good, we should **not** judge the theory itself.	1	2	3	4	5
20. Scientific knowledge is **not** a product of human imagination.	1	2	3	4	5
21. Scientific beliefs do **not** change over time.	1	2	3	4	5
22. There is an effort in science to build as great a number of laws, theories, and concepts as possible.	1	2	3	4	5
23. The evidence for scientific knowledge need **not** be open to public examination.	1	2	3	4	5
24. Relationships among the laws, theories, and concepts of science do **not** contribute to the explanatory and predictive power of science.	1	2	3	4	5
	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
25. Moral judgment can be passed on scientific knowledge.	1	2	3	4	5
26. A scientific theory is similar to a work of art in that they both express creativity.	1	2	3	4	5
27. Scientific knowledge is subject to review and change.	1	2	3	4	5
28. There is an effort in science to keep the number of laws, theories, and concepts at a minimum.	1	2	3	4	5
29. The evidence for scientific knowledge must be repeatable.	1	2	3	4	5
30. The various sciences contribute to a single organized body of knowledge.	1	2	3	4	5

	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
31. It is meaningful to pass moral judgment on both the applications of scientific knowledge and the knowledge itself.	1	2	3	4	5
32. Scientific knowledge is a product of human imagination.	1	2	3	4	5
33. Those scientific beliefs which were accepted in the past and since have been discarded, should be judged in their historical context.	1	2	3	4	5
34. If two scientific theories explain a scientist's observations equally well, the more complex theory is chosen.	1	2	3	4	5
35. Scientific laws, theories, and concepts are tested against reliable observations.	1	2	3	4	5
36. Biology, chemistry, and physics are similar kinds of knowledge.	1	2	3	4	5
	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
37. If the applications of a piece of scientific knowledge are generally considered bad, then the piece of knowledge is also considered bad.	1	2	3	4	5
38. Scientific knowledge does **not** express the creativity of scientists.	1	2	3	4	5
39. Scientific knowledge is unchanging.	1	2	3	4	5
40. Scientific knowledge is specific as opposed to comprehensive.	1	2	3	4	5
41. The evidence for a piece of scientific knowledge does **not** have to be repeatable.	1	2	3	4	5
42. Biology, chemistry, and physics are different kinds of knowledge.	1	2	3	4	5
	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
43. A piece of scientific knowledge should **not** be judged good or bad.	1	2	3	4	5
44. Scientific theories are discovered, **not** created by man.	1	2	3	4	5
45. We do **not** accept a piece of scientific knowledge unless it is free of error.	1	2	3	4	5
46. Scientific knowledge is comprehensive as opposed to specific.	1	2	3	4	5
47. Consistency among test results is a requirement for the acceptance of scientific knowledge.	1	2	3	4	5
48. The laws, theories, and concepts of biology, chemistry, and physics are interwoven.	1	2	3	4	5

Thank You!

Sept. 2003

APPENDIX B

SCED 401: Science Learning Environment & Attitude Survey

Directions for Students

We would like you to complete this questionnaire based on your experiences during your science capstone course (SCED 401—A Process Approach to Science) this semester.

This questionnaire contains statements about practices that may have taken place during this course. You will be asked how often each practice took place. There are no 'right' or 'wrong' answers. Your memories and/or opinions are what is wanted. Read each statement carefully, and think about how well each statement describes what **SCED 401** was like for you.

Draw a circle around

1	if the practice took place	**Almost Never**
2	if the practice took place	**Seldom**
3	if the practice took place	**Sometimes**
4	if the practice took place	**Often**
5	if the practice took place	**Almost Always**

Be sure to give an answer for all questions. If you change your mind about an answer, just cross it out and circle another. Some statements in this questionnaire are fairly similar to other statements. Don't worry about this. Surveys are constructed using similar questions multiple times. Simply give your opinion about all statements based on your experiences in SCED 401 this semester.

Background Information

Current SCED 401 INSTRUCTOR'S NAME (circle one):Colburn Martin McMahon Plumlee Saylor Writer

Your STUDENT ID #: ___ ___ ___ -____ ____ - ____ ____ ____ ____ Your Gender : Male Female

	DURING SCED 401…				
Student Cohesiveness	**Almost Never**	**Seldom**	**Some times**	**Often**	**Almost Always**
1. I made friends among other students.	1	2	3	4	5
2. I knew other students.	1	2	3	4	5
3. I was friendly to other students.	1	2	3	4	5
4. Other students were my friends.	1	2	3	4	5
5. I worked well with other students.	1	2	3	4	5
6. I helped other students who were having trouble with their work.	1	2	3	4	5
7. Students liked me.	1	2	3	4	5
8. I got help from other students.	1	2	3	4	5

	DURING SCED 401…				
Instructor Support	**Almost Never**	**Seldom**	**Some times**	**Often**	**Almost Always**
9. The instructor took a personal interest in me.	1	2	3	4	5
10. The instructor went out of his/her way to help me.	1	2	3	4	5
11. The instructor considered my feelings.	1	2	3	4	5
12. The instructor helped me when I had trouble with the work.	1	2	3	4	5
13. The instructor talked with me.	1	2	3	4	5
14. The instructor was interested in my problems.	1	2	3	4	5
15. The instructor moved about the class to talk with me.	1	2	3	4	5
16. The instructor's questions helped me to understand.	1	2	3	4	5
Investigation	**Almost Never**	**Seldom**	**Some times**	**Often**	**Almost Always**
17. I carried out investigations to test my ideas.	1	2	3	4	5
18. I was asked to think about the evidence for statements.	1	2	3	4	5
19. I carried out investigations to answer questions coming from discussions.	1	2	3	4	5
20. I explained the meaning of statements, diagrams and graphs.	1	2	3	4	5
21. I carried out investigations to answer questions that puzzled me.	1	2	3	4	5
22. I carried out investigations to answer the instructor's questions.	1	2	3	4	5
23. I found out answers to questions by doing investigations.	1	2	3	4	5
24. I solved problems by using information obtained from my own investigations.	1	2	3	4	5
Cooperation	**Almost Never**	**Seldom**	**Some times**	**Often**	**Almost Always**
25. I cooperated with other students when doing assignment work.	1	2	3	4	5
26. I shared my books and resources with other students when doing assignments.	1	2	3	4	5
27. When I worked in groups, there was teamwork.	1	2	3	4	5
28. I worked with other students on projects.	1	2	3	4	5
29. I learned from other students.	1	2	3	4	5
30. I worked with other students.	1	2	3	4	5
31. I cooperated with other students on class activities.	1	2	3	4	5
32. Students worked with me to achieve class goals.	1	2	3	4	5

	DURING SCED 401…				
Open-Endedness	**Almost Never**	**Seldom**	**Some times**	**Often**	**Almost Always**
33. There was opportunity for me to pursue my own science interests.	1	2	3	4	5
34. I was required to design my own experiments to solve a given problem.	1	2	3	4	5
35. Other students collected different data than I did for the same problem.	1	2	3	4	5
36. I was allowed to go beyond the regular laboratory exercises and do some experimenting of my own.	1	2	3	4	5
37. I did different experiments than some of the other students.	1	2	3	4	5
38. The instructor decided the best way for me to carry out the laboratory experiments.	1	2	3	4	5
39. I decided the best way to proceed during laboratory experiments.	1	2	3	4	5
Material Environment	**Almost Never**	**Seldom**	**Some times**	**Often**	**Almost Always**
40. I found that the laboratory was crowded when I was doing experiments.	1	2	3	4	5
41. The equipment and materials that I needed for laboratory activities were readily available.	1	2	3	4	5
42. I was ashamed of the appearance of the laboratory.	1	2	3	4	5
43. The laboratory equipment that I used was in poor working order.	1	2	3	4	5
44. I found that the laboratory was just the right temperature to work in.	1	2	3	4	5
45. The laboratory was an attractive place for me to work in.	1	2	3	4	5
46. My laboratory had enough room for individual or group work.	1	2	3	4	5
Enjoyment of Science Lessons	**Almost Never**	**Seldom**	**Some times**	**Often**	**Almost Always**
47. I looked forward to lessons.	1	2	3	4	5
48. Lessons in the class were fun.	1	2	3	4	5
49. I disliked lessons in the class.	1	2	3	4	5
50. Lessons in the class bored me.	1	2	3	4	5
51. The class was one of the most interesting college classes.	1	2	3	4	5
52. I enjoyed lessons in the class.	1	2	3	4	5
53. Lessons in the class were a waste of time.	1	2	3	4	5
54. The lessons made me interested in science.	1	2	3	4	5

SCED 401: Nature of Scientific Knowledge Survey

The following questionnaire contains 48 statements about the nature of scientific knowledge. Read each statement carefully, and based on the knowledge, skills, and experiences that you gained during the science capstone course (SCED 401—A Process Approach to Science), indicate whether you "strongly disagree," "disagree," "are neutral," "agree," or "strongly agree" with each statement. Some statements in this questionnaire are fairly similar to other statements. Don't worry about this. Simply give your opinion about all statements. Draw a circle around:

1 if you **strongly disagree** with the statement
2 if you **disagree** with the statement
3 if you are **neutral** about the statement
4 if you **agree** with the statement
5 if you **strongly agree** with the statement

	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
1. The applications of scientific knowledge can be judged good or bad; but the knowledge itself cannot.	1	2	3	4	5
2. Scientific laws, theories, and concepts do **not** express creativity.	1	2	3	4	5
3. We accept scientific knowledge even though it may contain error.	1	2	3	4	5
4. Scientific knowledge is stated as simply as possible.	1	2	3	4	5
5. Scientific knowledge need **not** be capable of experimental test.	1	2	3	4	5
6. The laws, theories, and concepts in biology, chemistry, and physics are related.	1	2	3	4	5
	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
7. It is incorrect to judge a piece of scientific knowledge as being good or bad.	1	2	3	4	5
8. Scientific knowledge expresses the creativity of scientists.	1	2	3	4	5
9. The truth of scientific knowledge is beyond doubt.	1	2	3	4	5
10. If two scientific theories explain a scientist's observations equally well, the simpler theory is chosen.	1	2	3	4	5
11. Consistency among test results is **not** a requirement for the acceptance of scientific knowledge.	1	2	3	4	5
12. The laws, theories, and concepts in biology, chemistry, and physics are **not** linked.	1	2	3	4	5
	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
13. Certain pieces of scientific knowledge are good and others are bad.	1	2	3	4	5
14. Scientific laws, theories, and concepts express creativity.	1	2	3	4	5
15. Today's scientific laws, theories, and concepts may have to be changed in the face of new evidence.	1	2	3	4	5
16. Scientific laws, theories, and concepts are **not** stated as simply as possible.	1	2	3	4	5
17. A piece of scientific knowledge will be accepted if the evidence can be obtained by other investigators working under similar conditions.	1	2	3	4	5
18. The laws, theories, and concepts of biology, chemistry, and physics are **not** related.	1	2	3	4	5

	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
19. Even if the applications of a scientific theory are judged to be good, we should **not** judge the theory itself.	1	2	3	4	5
20. Scientific knowledge is **not** a product of human imagination.	1	2	3	4	5
21. Scientific beliefs do **not** change over time.	1	2	3	4	5
22. There is an effort in science to build as great a number of laws, theories, and concepts as possible.	1	2	3	4	5
23. The evidence for scientific knowledge need **not** be open to public examination.	1	2	3	4	5
24. Relationships among the laws, theories, and concepts of science do **not** contribute to the explanatory and predictive power of science.	1	2	3	4	5
	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
25. Moral judgment can be passed on scientific knowledge.	1	2	3	4	5
26. A scientific theory is similar to a work of art in that they both express creativity.	1	2	3	4	5
27. Scientific knowledge is subject to review and change.	1	2	3	4	5
28. There is an effort in science to keep the number of laws, theories, and concepts at a minimum.	1	2	3	4	5
29. The evidence for scientific knowledge must be repeatable.	1	2	3	4	5
30. The various sciences contribute to a single organized body of knowledge.	1	2	3	4	5
	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
31. It is meaningful to pass moral judgment on both the applications of scientific knowledge & the knowledge itself.	1	2	3	4	5
32. Scientific knowledge is a product of human imagination.	1	2	3	4	5
33. Those scientific beliefs which were accepted in the past and since have been discarded, should be judged in their historical context.	1	2	3	4	5
34. If two scientific theories explain a scientist's observations equally well, the more complex theory is chosen.	1	2	3	4	5
35. Scientific laws, theories, and concepts are tested against reliable observations.	1	2	3	4	5
36. Biology, chemistry, and physics are similar kinds of knowledge.	1	2	3	4	5
	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
37. If the applications of a piece of scientific knowledge are generally considered bad, then the piece of knowledge is also considered bad.	1	2	3	4	5
38. Scientific knowledge does **not** express the creativity of scientists.	1	2	3	4	5
39. Scientific knowledge is unchanging.	1	2	3	4	5
40. Scientific knowledge is specific as opposed to comprehensive.	1	2	3	4	5
41. The evidence for a piece of scientific knowledge does **not** have to be repeatable.	1	2	3	4	5
42. Biology, chemistry, and physics are different kinds of knowledge.	1	2	3	4	5

	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
43. A piece of scientific knowledge should **not** be judged good or bad.	1	2	3	4	5
44. Scientific theories are discovered, **not** created by man.	1	2	3	4	5
45. We do **not** accept a piece of scientific knowledge unless it is free of error.	1	2	3	4	5
46. Scientific knowledge is comprehensive as opposed to specific.	1	2	3	4	5
47. Consistency among test results is a requirement for the acceptance of scientific knowledge.	1	2	3	4	5
48. The laws, theories, and concepts of biology, chemistry, and physics are interwoven.	1	2	3	4	5

Thank You!

APPENDIX C

Interview Questions for Participants in SCED 401— Fall 2003 Semester, Intervention Classes

1. What was your *previous* science laboratory class? What was the biggest difference between your *previous* science laboratory class and this course?

2. Did you have cooperative learning groups in your previous science laboratory course? *(If yes…)* How did the cooperative learning experience in this course compare to your *previous* science laboratory course?

3. One element in the survey includes statements about 'open-endedness'. *[Show student the scale and individual items in that scale.]* Would you have preferred more, less, or the same level of open-endedness in this course? Can you explain why you feel this way? How did the level of open-endedness in your *previous* science laboratory course compare with this course?

4. Another element in the survey includes statements about 'investigation'. *[Show Ss scale and individual items in that scale.]* What did you think of the investigations and experiments that we did in this course? How did the investigations and experiments in your *previous* science laboratory course compare with this course?

5. Dr. Peter Hodum's and my purpose in having you use the Antarctic seabird data during this course was to help you to feel like a scientist and to better understand how scientists do their work. Can you give me an example during the Seabird Project when you did in fact feel like a real scientist? Do you have any examples of an 'aha' moment during the Seabird Project when you understood something about scientific work that you had not previously realized?

6. Would you say that your attitude towards science has stayed the same, improved or declined as a result of taking this course? Can you describe what factors have contributed to this change?

APPENDIX D

CONSENT TO PARTICIPATE IN RESEARCH
SCED 401 Student Form[*]--Intervention Classes

Title of Study: Perceptions of the Learning Environment, Attitudes Towards Science, and Understandings of the Nature of Science Among Prospective Elementary Teachers in an Innovative Science Course

You are asked to participate in a research study conducted by Catherine Martin-Dunlop, full-time faculty member in the College of Natural Sciences & Mathematics at California State University, Long Beach, and a doctoral candidate at Curtin University of Technology, Perth, Western Australia. This research will be used for course and program evaluation purposes within the Science Education Department of the College, and will contribute to Catherine's doctoral dissertation. You were selected as a participant in this study because you are a current student enrolled in the course under investigation (SCED 401: A Process Approach to Science).

PURPOSE OF THE STUDY

The Science Education Department is in the process of evaluating all of its courses. This study is part of the self-evaluation. Its purpose is to describe and evaluate the impact of the course, SCED 401, on prospective elementary teachers' perceptions of the learning environment, attitudes towards science, and understandings of the nature of science. Associations between the learning environment and student outcomes (attitude and understanding of the nature of science) will also be explored. Comparisons will be made between students' *previous* science laboratory course and SCED 401 in terms of the identified variables. In Catherine Martin-Dunlop's sections of SCED 401, the effect of integrating real research data on Antarctic seabirds into the course and having a scientist co-teach the course will also be assessed.

PROCEDURES

Because this study is part of a self-evaluation process, you are required as part of the course to do items (1) and (2) as indicated on page 2. If you would ***also*** like to participate in Catherine Martin-Dunlop's dissertation work, you will do the following things:

Sign this consent form indicating your willingness to:

(1) Complete an in-class survey (15-20 minutes to complete) at the beginning of the course, and near the end of the course,
(2) Complete two online questions on the nature of science (10-15 minutes to complete) at the beginning and near the end of the course,

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[*] *Approved from February 13, 2003 to February 12, 2004 by the CSULB IRB.*

(3) Participate in a 30-minute interview that will be audiotaped,

POTENTIAL RISKS AND DISCOMFORTS

This study does not involve any foreseen risks to participants. All surveys and online questions will be numerically coded to retain confidentiality (i.e., names will not be used).

POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

The findings of this study will be used to describe and evaluate the effectiveness of SCED 401 in achieving its course goals, to improve the course for future SCED 401 students and, to benefit teacher education programs at other campuses that do not have an innovative course such as SCED 401 for prospective elementary teachers.

PAYMENT FOR PARTICIPATION

No payment is offered to you for your participation.

CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain strictly confidential. If direct quotes from the interviews are used in the dissertation manuscript or department reports, they will not identify the participant by name as to assure the anonymity of all participants.

You also have the right to review and/or edit the audiotape of the interview. Audiotapes will only be used for educational purposes associated with this research study.

PARTICIPATION AND WITHDRAWAL

Although participating in the Science Education Department's self-study is not optional, participating in Catherine Martin-Dunlop's research study is. If you volunteer to be in her study, you may withdraw at any time without consequences of any kind. Participation or non-participation in her study will not affect your grade, treatment, or any other personal consideration or right you usually expect. The investigator may withdraw you from this research if circumstances arise which in the opinion of the researcher warrant doing so.

IDENTIFICATION OF INVESTIGATOR

If you have any questions or concerns about the research, please feel free to contact Catherine Martin-Dunlop, Principal Investigator/Researcher at 562-985-4801 or by email at cmartin7@csulb.edu

RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time for Catherine Martin-Dunlop's study and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, contact the Office of University Research, CSU Long Beach, 1250 Bellflower Blvd., Long Beach, CA 90840; Telephone: (562) 985-5314 or email to research@csulb.edu.

SIGNATURE OF RESEARCH PARTICIPANT

For each phase of the study that involves your participation, informed consent is required. In the spaces provided below, please indicate your willingness to participate by placing your initials.

(1) Completing the paper-and-pencil survey entitled *Science Learning Environment and Attitude Questionnaire* and *Nature of Scientific Knowledge Survey*
____________ Initials

(2) Completing the online questions on the nature of science

____________ Initials

(3) Participate in an interview that will be audiotaped

____________ Initials

I understand the procedures and conditions of my participation described above. My questions have been answered to my satisfaction, and I agree to participate in this study.

__________________	______________________________	_______________
Name of Participant	Signature of Participant	Date

APPENDIX E

CONSENT TO PARTICIPATE IN RESEARCH
SCED 401 Student Form[*]*--Nonintervention Classes*

Title of Study: Perceptions of the Learning Environment, Attitudes Towards Science, and Understandings of the Nature of Science Among Prospective Elementary Teachers in an Innovative Science Course

You are asked to participate in a research study conducted by Catherine Martin-Dunlop, full-time faculty member in the College of Natural Sciences & Mathematics at California State University, Long Beach, and a doctoral candidate at Curtin University of Technology, Perth, Western Australia. This research will be used for course and program evaluation purposes within the Science Education Department of the College, and will contribute to Catherine's doctoral dissertation. You were selected as a participant in this study because you are a current student enrolled in the course under investigation (SCED 401: A Process Approach to Science).

PURPOSE OF THE STUDY

The Science Education Department is in the process of evaluating all of its courses. This study is part of the self-evaluation. Its purpose is to describe and evaluate the impact of the course, SCED 401, on prospective elementary teachers' perceptions of the learning environment, attitudes towards science, and understandings of the nature of science. Associations between the learning environment and student outcomes (attitude and understanding of the nature of science) will also be explored. Comparisons will be made between students' *previous* science laboratory course and SCED 401 in terms of the identified variables.

PROCEDURES

Because this study is part of a self-evaluation process, you are required as part of the course to do items (1) and (2) as indicated on page 2. If you would ***also*** like to participate in Catherine Martin-Dunlop's dissertation work, you will do the following things:

Sign this consent form indicating your willingness to

(1) Complete an in-class survey (15-20 minutes to complete) at the beginning of the course, and near the end of the course,

(2) Complete two online questions on the nature of science (10-15 minutes to complete) at the beginning and near the end of the course.

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[*] *Approved from February 13, 2003 to February 12, 2004 by the CSULB IRB.*

POTENTIAL RISKS AND DISCOMFORTS

This study does not involve any foreseen risks to participants. All surveys and online questions will be numerically coded to retain confidentiality (i.e., names will not be used).

POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

The findings of this study will be used to describe and evaluate the effectiveness of SCED 401 in achieving its course goals, to improve the course for future SCED 401 students, and to benefit teacher education programs at other campuses that do not have an innovative course such as SCED 401 for prospective elementary teachers.

PAYMENT FOR PARTICIPATION

No payment is offered to you for your participation.

CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain strictly confidential.

PARTICIPATION AND WITHDRAWAL

Although participating in the Science Education Department's self-study is not optional, participating in Catherine Martin-Dunlop's research study is. If you volunteer to be in her study, you may withdraw at any time without consequences of any kind. Participation or non-participation in her study will not affect your grade, treatment, or any other personal consideration or right you usually expect. The investigator may withdraw you from this research if circumstances arise which in the opinion of the researcher warrant doing so.

IDENTIFICATION OF INVESTIGATOR

If you have any questions or concerns about the research, please feel free to contact Catherine Martin-Dunlop, Principal Investigator/Researcher at 562-985-4801 or by email at cmartin7@csulb.edu

RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time for Catherine Martin-Dunlop's study and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, contact the Office of University Research, CSU Long Beach, 1250 Bellflower Blvd., Long Beach, CA 90840; Telephone: (562) 985-5314 or email to research@csulb.edu.

SIGNATURE OF RESEARCH PARTICIPANT

For each phase of the study that involves your participation, informed consent is required. In the spaces provided below, please indicate your willingness to participate by placing your initials.

(1) Completing the paper-and-pencil survey entitled *Science Learning Environment and Attitude Questionnaire* and *Nature of Scientific Knowledge Survey*

____________ Initials

(2) Completing the online questions on the nature of science.

_____________ Initials

I understand the procedures and conditions of my participation described above. My questions have been answered to my satisfaction, and I agree to participate in this study.[*]

__________________	______________________________	_______________
Name of Participant	Signature of Participant	Date

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[*] *Approved from February 13, 2003 to February 12, 2004 by CSULB IRB.*