Use of dendrochronology to promote understanding of environmental change

Cynthia Stager McCormick
Louisiana State University and Agricultural and Mechanical College

Follow this and additional works at: https://digitalcommons.lsu.edu/gradschool_dissertations
Part of the Education Commons

Recommended Citation
https://digitalcommons.lsu.edu/gradschool_dissertations/2689

This Dissertation is brought to you for free and open access by the Graduate School at LSU Digital Commons. It has been accepted for inclusion in LSU Doctoral Dissertations by an authorized graduate school editor of LSU Digital Commons. For more information, please contact gradetd@lsu.edu.
USE OF DENDROCHRONOLOGY
TO PROMOTE
UNDERSTANDING
OF ENVIRONMENTAL CHANGE

A Dissertation

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

In

The Department of Educational Theory, Policy, & Practice

By

Cynthia Stager McCormick
B.A., Berry College, 1973
M.S., Virginia Tech, 1977
Ed.S., Louisiana State University
August, 2007
Acknowledgements

Completing this dissertation has been a long journey but there are a number of people who made the trip a lot easier. First on my list of people to thank must be husband, Mike, who has been a great support and epitomizes what an encourager should be. I also would like to thank my children, Jake and his wife Abby, Jessica and Brandon. They have been very supportive and truly picked up my spirits when I needed it most. Additionally, I would like to thank my mother, Virginia, who always makes me think that I can do anything I want.

I am also very appreciative of Dr. Jim Wandersee who served as my major professor as I developed and worked through this research. He and the members of my committee, including Dr. Pamela Blanchard, Dr. Earl Cheek, Dr. Terri Poehl, and Dr. Rita Culross, were very generous and most astute with the advice they gave me in developing this project.

I must also thank the faculty and staff at Franklinton High School where I have been employed while I worked on my doctorate. They have been very sympathetic with my trials along this educational journey. I particularly wish to thank my principal Ms Beverly Young who is very much in favor of professional growth and the science department who have provided advice and served as a sounding board throughout this research.

Lastly I would like to say thanks to Mrs. Cheryl Bruton and her environmental science classes for participating in this research. Mrs. Bruton’s enthusiasm for both her students and environmental science greatly improved the quality of this research and the students’ willingness try new learning strategies made this research possible.
# Table of Contents

ACKNOWLEDGEMENTS................................................................. ii

ABSTRACT................................................................................... viii

INTRODUCTION............................................................................... 1
   Quality of Science Education.................................................. 1
   Science Curriculum................................................................. 4
   Science Laboratories............................................................... 6
   Motivation.................................................................................. 7
   Research Overview................................................................. 9
   Setting..................................................................................... 10
   Significance of This Study....................................................... 11

LITERATURE REVIEW.............................................................. 13
   Learning Theories .................................................................... 13
      Piaget.................................................................................... 13
      Bruner.................................................................................. 15
      Ausubel............................................................................... 16
      Novak............................................................................... 17
   Constructivism......................................................................... 19
      Constructivist Foundations.................................................. 20
      Constructivist Perspective................................................... 20
      Constructivist Strategies..................................................... 21
      Criticisms of Constructivism............................................... 23
   Meaningful Learning and Conceptual Understanding............... 24
      Meaningful Learning............................................................ 24
      Conceptual Understanding.................................................. 25
      Learning Style...................................................................... 26
      Motivation............................................................................. 27
   Brain Research and Learning.................................................. 28
   Visualization............................................................................ 29
   Inquiry.................................................................................... 31
      History of Inquiry............................................................... 33
      Impact of Inquiry on Science Literacy.................................... 35
      Roger Bybee's 5E Learning Cycle.......................................... 36
   Assessment............................................................................. 37
      Tyler.................................................................................... 39
      No Child Left Behind........................................................... 42
      Criticisms of the Tyler Rationale.......................................... 44
Summary

RESULTS

Overview
Participant Description
Students
Instructor
Student and Teacher Interviews
First Student Interview
Second Student Interview
Third Student Interview
Teacher Interview
Webquest and Roundhouse Diagrams
Cross-sectional Comparisons
Statistics and Climate Activity
Climate Change PowerPoint
Inquiries
“Effects of Trees on Soil Chemistry”
“Are Polluted Leaves Different from Nonpolluted Leaves?”
“Does Sunlight Affect Tree Growth?”
“Do Trees Grow Better at the Bottom or Top of a Hill?”
“Does Competition Affect Tree Growth?”
“Does Species Effect Tree Growth”
Researcher Observations
Exit Slips
Pre- and Posttest
Pre- and Posttest Description
Pretest
Posttest
Comparison of Test Scores
Statistical Analysis of Scores
Summary

DISCUSSION AND CONCLUSIONS

Research Question One
Research Question Two
Research Question Three
Research Question Four
Conclusion

LITERATURE CITED
APPENDIX V: SURVEY INSTRUMENTS......................................................... 171
APPENDIX W: PRETEST.............................................................................. 176
APPENDIX X: POSTTEST............................................................................. 181
APPENDIX Y: STUDENT ARTIFACTS......................................................... 186
APPENDIX Z: RUBRICS FOR STUDENT ACTIVITIES............................... 192
APPENDIX AA: MODEL DIAGRAM OF A TREE CROSS SECTION............. 194
APPENDIX BB: CLIMATE CHANGE POWERPOINT................................... 195
APPENDIX CC: EXPERIMENT EVALUATIONS ........................................ 206
APPENDIX DD: COMPARISON OF PRE- AND POSTTEST....................... 207
APPENDIX EE: PROFILE OF INTERVENTION ACTIVITIES....................... 208
VITA............................................................................................................ 210
**Abstract**

The purpose of this research was to determine how dendrochronology can be used in an experiential unit to enhance high school students’ understanding of environmental change. Dendrochronology, the visual examination of tree ring cross sections provides opportunities to relate environmental change to growth patterns of trees and can be used to show the students both how scientists can investigate the past and how the environment can affect trees. Students engaged in a 10-day unit that employed a variety of constructivist learning activities to investigate environmental change, climate change, and tree growth. The culminating activity was student-created experiments that investigated various aspects of the relationship of trees to their environment.

This research was a mixed method design and was conducted at a small public high school in the Deep South. The school is a Title One school on a four by four block schedule and is located in a rural area where forestry is one of the major industries. Twenty five juniors and seniors who were members of two environmental science classes were the participants in the research.

As evaluated by the Wilcoxon matched-pair signed rank test, students scored significantly higher on the posttest (P < .01) than on the pretest with average scores of 9.52 on the pretest and 18.76 on the posttest. Most of these gains were in questions that evaluated the students understanding of climate change, tree anatomy and statistical analyses of tree growth data. The qualitative components of the research supported that these were the areas of greatest growth and revealed that the students greatly enjoyed participating in investigations of their own.
Introduction

Two of the major concerns in the United States are the declining quality of education of our youth and the escalating deterioration of our environment. One of the most obvious places to address these two issues is the science classroom. However, for teachers to be successful, they must engage the students in units that will address both issues in a way that promotes student commitment to the project, ensures meaningful learning, strengthens scientific literacy, and provides students with tools for making long-term decisions on global environmental problems. Choosing topics that are relevant to students and that give students visual evidence of environmental change are ways of more actively engaging students in science in a way that promotes life long learning. Presenting the material in a way that allows the students to design their own questions and search for answers themselves will benefit the students by encouraging them to think as scientists think. In areas in which forestry is a major industry, use of dendrochronology, the study of tree rings to determine the effect of environmental and climate change, appears to be a means of making science relevant to the students while simultaneously making them conscious of the environmental changes and climatic changes that are occurring in their world. Accordingly, the purpose of this research was to determine how participation in an experiential unit on the use of dendrochronology to investigate environmental change affects student understanding of environmental change.

Quality of Science Education

The quality of education, specifically, in science, is an area of disquiet that has been addressed by a number of organizations and over a considerable length of time, yet the improvement in science education is rather slow. One such organization, the
Business-Higher Education Reform (BHER), is concerned that poor student achievement in mathematics and science threatens the performance of our business community, the U.S. economy and the quality of our lives (Business-Higher Education Forum, 2005). The BHER reported that in the 2004 Program for International Student Assessment, the problem-solving skills of tenth grade students in American were lower than 25 other countries and only 42% were shown to be capable of solving problems at even the lowest level of problem-solving tested in this study. The BHER cited that, concomitantly, the U.S. Department of Labor predicted that by the year 2008, jobs in the scientific and technical fields will increase at a rate of four times that of other jobs resulting in a 52% increase in these types of jobs, which translates into approximately six million job opportunities. These authors reported that the National Assessment of Educational Progress (NAEP) test of 2000 indicated that only 20% of our high school seniors were proficient in mathematics. Science scores were similarly dismal. In 2003, corresponding proficiency rates on the NAEP were only 30% for students in the fourth and eighth grade.

Though eloquently stated by the BHER (2005), these concerns are not theirs alone. Similar concerns for science education are expressed in an ACT report released in October 2004 (ACT, 2005). These test administrators stated that only 26% of the 1.2 million high school graduates who took the ACT assessment in 2004 could be expected to earn a C or better in their beginning college biology course. They reported that 25% of college freshmen at four-year schools and a shocking 50% of those attending a two-year community college did not return their sophomore year. Nelson (1999) stated that the United States ranked among the lowest of a group of 21 nations that were tested in the
Third International Math and Science Survey (TIMSS) and that American students taking advanced placement mathematics and physics placed lower than corresponding students in other nations. He stated that these statistics simply verify the fact that students in the United States are not grasping the knowledge from mathematics, science and technology they need in order to be successful. The No Child Left Behind Act is another indicator of the public’s concern for education of our youth (United States Department of Education, 2005). This legislation advocates the need for improvement of all students and focuses on the improvement of student growth in reading and mathematics but should not be restricted to these areas.

The disquiet illustrated by these authors is not a recent development. The lackluster performance of American science students has been an issue for a number of years, dating back to 1958 when the launch of Sputnik prompted the enactment of the National Defense Education Act to improve, among other things, science education (Clifford & Guthrie, 1990). Disturbed over science education, the American Association for Advancement of Science Education established Project 2061 in 1985. In the preface, this organization stated that “the present curricula in science and mathematics are overstuffed and undernourished” (xvi) and that the present textbooks and methods of instruction often impede progress toward science literacy (American Association for the Advancement of Science, 1990).

The distress over the quality of science education was beautifully expressed by the Wall Street Journal in the statement, “If there is one thing about science that educators and scientists wish students would learn, it isn't the difference between an isotope and an isomer or any of the hundreds of other facts that pepper textbooks and
tests. It is how to think critically about scientific data and concepts and be able to synthesize and apply them” (Begley, 2004). Thus, it is apparent that for education to improve teachers need to be steered away from teaching for rote memory and teaching the test.

In the sciences, including mathematics and technology, our focus should be to guide students in such a way that they can develop understandings and scientific habits of mind that will help them think for themselves. The BHER suggests that students should be allowed to participate in experiences that increase interest and understanding of math and science concepts through active participation in investigations that promote problem solving abilities and improves understanding of key concepts and have real world applications (Business-Higher Education Forum, 2005). Evidently the ACT also feels that more science training is needed. In their 2005 report, they expressed the opinion that additional training in science through just one additional course could boost college readiness (ACT, 2005).

Science Curriculum

In addition to an anxiety over the depth of science learning, another concern is that of choosing a curriculum that fits the needs of our students. Though the traditional areas of biology, chemistry and physics are still essential, the study of environmental science is becoming more and more necessary. This is reflected in the National Science Education Standards in which the National Research Council (1996) included a content standard for personal and social perspectives in which they recommend that students in high school expand their understanding of concepts such as population, natural resources,
environmental quality and the role of science and technology in national and global challenges.

Even though the global environmental outlook is less than bright today, the outlook for the second half of the 21st century is even dimmer. Specific concerns include increased chemical contaminants in our underground water supply, increased flood damage due to global warming, disposal of increasing solid municipal waste, loss of farmland due to urbanization and erosion, depletion of nonrenewable resources without adequate replacements, and climate change due to global warming (Blatt, 2005). Blatt states that as our world continues to change, the existence of all Earth’s creatures is threatened by issues such as unchecked population growth, acid rain, shrinking tropical rain forests, pollution, disease, social strife, extreme inequities, war, global warming, nuclear waste and the shadow of nuclear holocaust.

At the current time, public awareness and understanding of environmental concerns is ambivalent. Blatt (2005) reported that a Gallup poll of 2002 indicated that 63% of Americans would be willing to roll back the 2002 tax cuts in an attempt to protect the environment and Pompe and Rinehart (2002) found that Americans favor higher emission and pollution standards and stronger enforcement of these same regulations. Yet Blatt reports that many American citizens commonly believe that environmental regulations cause widespread unemployment, plant shutdowns and emigration of companies to countries with less stringent requirements. These incongruous views of the American public indicate an obvious need for more literacy on environmental issues.
Science Laboratories

One important area of science instruction is the use of the laboratory. The National Research Council (NRC) (2005) suggests that laboratory experiences allow students to use material world tools and techniques while directly working with the models and theories of science. An important role of the laboratory activity is to give students real opportunities to practice the science process and interact with the natural world. The NRC advocates the use of the laboratory as a way to help students master content, develop scientific reasoning, practice laboratory skills, understand the nature of science, nurture an interest in science and develop teamwork skills. Unfortunately these researchers feel that the current status of science laboratory work is poor with partial blame assigned to the undergraduate education of science teachers.

The NRC also cites the organization and structure of high schools as an inhibitor to improvement of science lab instruction. They find that teachers are insufficiently prepared to assess student performance of laboratory experiences and that continuing education needs to be provided to prepare teachers to present better laboratory experiences. High school laboratory experiences should be designed with clear goals in mind, should be well integrated with classroom science instruction, should integrate science content and process and allow for continuous student reflection and discussion. The NRC advises that sound laboratory experiences are those that are student centered and may include opportunities to access large data bases and interaction with real world data or simulations.
Motivation

No matter how dire the need for education on environmental issues, no curriculum will be successful unless the students buy into the program. According to Hodson (1998), the way a student responds to a learning situation depends on how the concepts taught fit the student’s goals and aspirations and the position he chooses to use will dictate the depth with which he learns the material. The depth may be rote learning, deeper learning or finding personal significance of the material. Hodson suggests that two possible ways to maximize the students’ willingness to learn is to choose a curriculum that they value or to raise student expectancy level by allowing everyone a chance to succeed. Since, according to Aikenhead (1994), students value aspects of science such as social, global, aesthetic and humanitarian over traditional science content, selection of curriculum that focuses on factors such as environmental change can increase student motivation resulting in a desire to make learning more meaningful.

Because both personal interest and social ramification affect the depth with which students learn material, curriculum that ties personally to the student and addresses environmental interest should motivate students to learn. Since forestry greatly affects the economy of the state of Louisiana, dendrochronology is a branch of forestry that fits the profile of a topic that addresses a variety of environmental issues and is personally connected to many Louisiana students. Vlosky (2005) in a Louisiana Ag Outlook Conference stated that 13.8 million acres, almost 50%, of Louisiana’s total land area are in forest and that 59 of the 64 parishes contain forestland. This makes forestry Louisiana’s second largest employer with almost 20,000 jobs in manufacturing and 8,000 in harvesting and transporting forest products. At the same conference, Moore (2005), the
president of the American Forest and Paper Association, said that almost $6 billion of Louisiana’s annual sales come from forest products.

Though the need for improvement in science education is well-documented, evidence of improvement has not occurred and the means for attaining this achievement is not clear. If one considers the statement, “If we aim to produce rationally-based conceptual change in students, then… the content of science courses should be such that it renders scientific theory intelligible, plausible and fruitful,” units that actively engage the students in a way that they deem important is a must (Strike & Posner, 1982, p.238). It is evident that students are more likely to learn when student motivation is activated and when choice of instructional tools can promote depth of learning and can encourage student metacognition. Units that allow alternative means of assessment and provide authentic science activities may improve student success. One possible unit that can provide such an opportunity is dendrochronology.

Dendrochronology is a topic that is rarely addressed in the high school science classroom yet it provides a chance for students to participate in active learning activities that engage the students in multiple ways with a visual component that improves learning. As shown in Appendix A, dendrochronology is a means of studying the age of trees and relating the trees growth to environmental factors. Dendrochronology can be used to create curricula that address both local and global issues, provide visualization of phenomena, and can be presented in a way that connects to student prior knowledge, encourages scientific thinking, addresses individual differences and allows students to be successful.
Research Overview

The Gowin Vee diagram, (shown in Appendix B), this research addresses the question of how dendrochronology affects student understanding of environmental change. Based on the ideas of Novak, Ausubel and Kolb, the theoretical underpinning of the study is that students learn best when actively participating in learning activities that provide visual clues to the concepts taught, motivate the students through addressing issues relevant to the students and allow students to build new concepts on prior knowledge. Consequently the primary purpose of the study was to determine the value added to students’ understanding of environmental change when an innovative experiential unit on dendrochronology is included in a high school environmental science course. The specific questions to examined were:

1. Can an in-depth experiential dendrochronology unit be designed that incorporates a number of national science standards?

2. What value does each component of the unit and the unit in toto add to student understanding of environmental change as measured by pre and post tests issued to participants, interviews with teachers and students and anecdotal notes?

3. Do student-constructed, small-multiple graphic representations of their own tree ring pattern data add value to student understanding of environmental change?

4. Does a culminating investigation into the effects of environmental change on tree growth add appreciable value to the unit’s contribution to student understanding of environmental change?

The following objectives were used to address these questions of the study.
1. Describe environmental science teacher who participated in the study by teaching the experimental dendrochronology unit in environmental science in terms of personal, professional and school demographic characteristics

2. Describe high school environmental science students who participate in the experimental dendrochronology unit in environmental science in terms of age, sex, race, socioeconomic status, grade point average and standardized test scores.

3. Use human constructivism ideas to design a high school environmental science instructional unit on dendrochronology that addresses national standards, integrates science and mathematics learning and contains multiple metacognitive and meaningful learning strategies such as vee diagrams, journaling and student designed inquiry and uses a variety of alternative assessments.

4. Assess the affective and instructional value of a high school environmental science instructional unit on dendrochronology through analysis of interviews given to participating environmental science teachers and selected students.

5. Analyze pre- and posttests that addresses both environmental standards and science processing skills to assess the instructional value of a high school environmental science instructional unit on dendrochronology on the high school environmental science students participating in the course.

6. Describe and analyze the graphic representations constructed by the high school environmental science students participating in a high school environmental science.

Setting

The study was conducted at a rural high school in the Deep South where forestry and forestry products are a dominant industry. The school is a Title One school with a
high poverty level where more than 90% of the students receive free or reduced lunch. The school typically offers four sections of environmental science per year. Although sections generally average 16 to 24 students, the actual number of students enrolled varies annually. Environmental science classes were chosen since this is frequently the last science class which many students take, the curriculum provides more flexibility for innovative inquiry studies and the national standards of environmental science most closely fit the objectives of the proposed unit. All personal information obtained was kept confidential and posed no ethical threats to any of the participants.

Significance of This Study

The national science standards stress that the underlying concepts and procedures taught should help students build an understanding of the underlying framework of ideas, connecting principles between science disciplines and an awareness of the change, constancy and evolution of scientific ideas (National Research Council, 1996). The National Research Council suggests that the goal of school science is to prepare students who can appreciate the natural world, use scientific reasoning to make personal decisions and participate in activities of scientific concern. Because learning science is an active endeavor that involves all students and because environmental issues are a mounting concern, science units should actively engage all students in a way that improves their awareness and concern for the natural world and its future. Accordingly, this study is designed to provide an opportunity for students to develop environmental science understandings through participation in an inquiry-based unit on dendrochronology. In the study, the research modeled human constructivist philosophy and teaching strategies that have been documented to promote active, meaningful learning in a way that help
students develop lifelong learning skills. Because dendrochronology is a topic that is relevant to the everyday life of students and has a visible nature it was expected that students would develop a better understanding of environmental change than is the general practice.
Literature Review

Learning Theories

In developing a new curriculum, unit of study or lesson for science or any other discipline, beginning with a sound educational theory can guide praxis and focus the intent of the mission so that the outcome can be as close to the ideal as possible. As Renner and Marek (1989) suggested, educational theory should have purpose, scientific discipline and a model for learning. Choosing an appropriate theory on which to base educational practice can be crushing without an understanding of the various educational theories and their application to the classroom. Educational theory has long been a topic of discussion in science education but some of the most frequently cited in the science education field include Jean Piaget, Jerome Bruner, David Ausubel, and Joseph Novak. In researching the theories of each of these researchers, a chronological approach is quite helpful. However an element of comparison needs to be included since the ultimate personal theory of learning may actually be a conglomerate of different facets of each of the aforementioned colored with the experience of the individual developing the theory. Appendix C is an overview of their learning theories and shows the important contributions of each researcher.

Piaget. The Swiss psychologist Jean Piaget’s training as a biologist strongly influenced his understanding of cognitive development in that he believed that behavior and biological acts are means of adaptation to the demands of the environment. These principles of adaptation and organization served as the background for his theory of cognitive development (Parsons, Hines & Sardo-Brown, 2001). Piaget identified four concepts involved with learning which he called schema, assimilation, accommodation
and equilibration. When an individual is exposed to a new idea or experience, the mind organizes these ideas into a cognitive structure called a schema that allows the mind to understand the experience and adapt to the experience. Any new experience that the individual encounters is organized into the existing schemata by either assimilation or accommodation. The process of integrating new knowledge into existing knowledge is referred to as assimilation whereas accommodation occurs when no schema exists on which to build the new information. Equilibration, which is a balance of assimilation and accommodation, must exist for optimal cognitive growth to occur. The child will experience cognitive disequilibrium when a new experience is different from what he expects. The child will adapt to the new situation by assimilating or accommodating the new experience and achieve a new state of cognitive equilibrium.

As described by Parsons, Hines and Sardo-Brown (2001), Piaget also identified four stages of development that should be considered in cognitive growth. The first stage of development is the sensorimotor stage in which the infant moves from reflexive activities to more organized forms of activity in which the child realizes that he is separate from the rest of the world. The second stage of development is the preoperational stage in which the child lacks logical operational skills and acts solely on his own perceptions. In the third stage of development, called the concrete operational stage, a child is able to act logically only on concrete problems. The fourth stage of cognitive development is called the formal operational stage in which a child is able to think logically on abstract concepts. Piaget’s theory has been criticized for its limited number of students, for treating learning and teaching as separate entities, for not considering the child’s way of thinking (Shapiro, 1994) and for its failure to recognize
differences in individuals due to prior knowledge (Mintzes & Wandersee, 1998). However, an important consequence of Piaget’s work is the development of the clinical interview.

The epistemology of the Piagetian constructivism considers knowledge as a continuous process that begins as a child and continues through adulthood with each piece of knowledge being built on prior knowledge and serving as an anchor for future knowledge. Based on this theory of learning, intellectual construction is normative, must occur through action, comes from the act of making connections, is a search for coherence and occurs in the epistemic subject (Smith, 1993).

Bruner. Although Jerome Bruner was responsible for disseminating the work of Piaget in the United States, he also constructed a developmental model that proposed that our perceptions and motivation to perceive changed developmentally (Bruner, 1960). He emphasized learning the structure of a subject so that other concepts could be built on this structure and so that the learner could see how ideas were related. He strongly supported the role of visualization in learning. Additionally, he advocated allowing students to develop the skills of scientists through participating in science activities, instilling an intrinsic interest in the subject, and he insisted that even young children could learn important scientific concepts when presented in an appropriate fashion (Mintzes & Wandersee, 1998). Bruner rightfully felt that motivation was necessary for the best learning and that insightful experience promoted interest and motivation. Motivation has long been considered a means of improving student participation and concern for learning. In one such instance, Lubben et al. (1996) found that students displayed more positive attitudes toward lessons when they were allowed to work on personally useful
applications, could own the activity by contributing their expertise and knowledge and could discuss contentious issues. Motivation and student enjoyment also increase when instruction involves everyday contexts in science teaching (Campbell, et. Al, 1994). These authors indicated that the improved responsiveness of students could result through increasing relevance. The work of Peacock (1995) showed that contextualization encourages access to knowledge and that contextualization is particularly appropriate for curriculum regionalization. Consequently, experiences that provoked a child would result in more meaningful learning. These ideas were used to develop Bruner’s discovery-learning model, which is built on a constructivist premise. In this model, the student links new information to prior knowledge through a teacher constructed discovery that allows the student to organize the information in a personal way (Parsons, Hinson, & Sardo-Brown, 2001). However, discovery type learning frequently is time consuming and, because it is directed by the student’s interests, may not result in a balanced base of learning.

Ausubel. David Ausubel introduced a theory of meaningful learning in 1962 that addresses the acquisition and use of knowledge and serves as the foundation for his cognitive assimilation theory (Novak, 1998). He suggests learning is an active construction of knowledge by the learner. An important aspect of this theory is that it recognizes that the most important influence on learning are what is already known, that learning is an interrelationship of knowing, feeling, and acting, and that there is a difference in rote learning and meaningful learning which is the substantive incorporation of new ideas into the learner’s knowledge structure (Ausubel, 1978).
Ausebel further postulated that meaningful learning can be subdivided into subsumptive learning and superordinate learning. With subsumptive learning, also called assimilation, students add to their basic knowledge bank. With superordinate learning, students have little or no experience with the concepts and must find ways of organizing the new concepts to fit with old concepts.

Key to Ausubel’s learning theory is the idea of organization. According to Ivie (1998), Ausubel views knowledge as an integrated system in which ideas are linked systematically. Knowledge can be envisioned as a hierarchical scheme in which major conceptual ideas serve as anchors on which to add new information. Consequently activities in which students are encouraged to organize their own thoughts would seem beneficial in helping them achieve meaningful learning. These might include concept maps and flow charts. Additionally, providing students with opportunities to connect new ideas to previous knowledge should also promote learning.

Novak. Joseph Novak believes that, when compared to rote learning, meaningful learning has the advantages of being retained longer, adding more capacity for later learning through the differentiation of subsumers, facilitating new learning and increasing transferability. His ideas of education involve human constructivism, and can be described as “a view of meaning making encompassing both a theory of learning and an epistemology of knowledge building” (Mintzes & Wandersee, 1998, p. 47). An overview of his ideas of human constructivism is described in the concept map of Appendix D, which shows his concern for how knowledge is scaffolded. In his theory of education, he states that “meaningful learning underlies the constructive integration of thinking, feeling, and acting leading to human empowerment for commitment and responsibility”
This author has defined meaningful learning as the incorporation of knowledge into their cognitive structure in a generalized and logical fashion in order to integrate the knowledge into a conceptual framework that is well connected to what they already know. The degree to which meaningful learning occurs depends on both the learner’s approach and the instructional tactics used. Mintzes and Wandersee (1998) justifiably consider human constructivism the best framework for teachers who wish to make instructional decisions based on understanding and conceptual change.

Incorporation of Novak’s theory of education in a unit on dendrochronology dictates that the materials to be taught should contain relevance to the students, should personally connect, should actively involve the students, should access prior knowledge, provide opportunities to right misconceptions, provide means for scaffolding new learning to prior knowledge and offer ways for the students to monitor their own achievement.

One of the dilemmas in developing a learning theory for science is the degree of guidance one should provide a student of science. On one hand, Mintzes and Wandersee suggest that when students are allowed to work with the content of science without structure, the students do acquire knowledge but the resulting information may contain misconceptions and partial understandings. Conversely, they indicate that a teaching strategy of inform-verify-practice may be considered sufficient if the main purpose it to simply inform about science. Yet, this mode of instruction misses the currently prominent component of science literacy that is the ability to solve problems through critical and independent thinking (AAAS, 1990). Renner and Marek (1989) offer a model of learning that allows students to work with the content of science while being directed by an instructor toward specific learning activities. This mode of instruction involves a cycle in
which the students are provided opportunities to explore, conceptualize and expand on a concept and is supported by the ideas of Piaget’s developmental learning theory of assimilation, accommodation and organization.

The literature supports the idea that students construct their own learning through active engagement of meaningful activities that allow students to be aware of their own thinking and to incorporate new concepts into their metacognitive structure either through building onto prior knowledge or by reconstructing or modifying what they already know. Current literature suggests that students learn best when the structure is of their own making, but it seems that the instructor must be the catalyst or provide some impetus in instances when a student seems to have no grasp of where to start or has no prior knowledge on which to build.

**Constructivism**

Constructivism is a term that can be used to describe a theory about how people learn but may also be used to address teaching strategies that address constructivist ideas (Colburn, 2000). Perhaps this stems from the fact that the theory of constructivist learning is based on the idea that people construct their own learning, consequently it is difficult to separate theory and practice. Based on the publications of the AAAS (1990, 1993) and the NRC (1996, 2000) constructivism has become the favored mode of instruction in science classrooms. The advantages of constructivism are touted as being able to produce students who are independent problem solvers and more ready for the real world. Thus an understanding of the theory and practices of constructivism as well as the history of constructivism should become an important aspect of a science teacher’s training.
Constructivist Foundations. Although constructivism in education is founded on the work of Jean Piaget’s cognitive development theories, departures do exist between the ideas of Piaget and constructivists. One departure is that constructivism is concerned with the way in which new knowledge is built on prior knowledge whereas Piaget did not account for individual differences or prior knowledge (Mintzes & Wandersee, 1998). Another difference is that constructivists consider knowledge as a social and shared entity whereas Piaget approached knowledge as an impersonal body of knowledge (Shapiro, 1994). Despite these departures, Piaget as well as other educators and philosophers such as John Dewey, Gilbert and Watts, Magoon, Pope, von Glaserfield, George Kelly and others have all influenced the constructivist way of thinking (Shapiro, 1994).

Constructivist Perspective. Kickbusch (1996) regards Berger and Luckmann as the authors of the social constructivist ideas that undergird the constructivists’ ideas employed in science classroom today. These authors propose that each person develops his own sense of understanding and that this knowledge is socially constructed. The constructivist perspective on learning is based on the argument that learning and teaching should start with what the pupil brings to the learning. The constructivist viewpoint of learning and the strategies that promote learning support the idea that what we learn depends on our own vision of the world and prior knowledge.

Because all learners see things differently they will construct knowledge in a way that is uniquely their own (Colburn, 2000). Since students come to a learning situation with prior ideas about science, they may have alternative views of science that could be contrary to widely supported scientific ideas and may be difficult to change. In a constructivist mode of science teaching, the role of the teacher is to help the students
align their personal beliefs about how the world works with those of the scientific
community. Aligning real world knowing with what is taught in the classroom is often
difficult, and frequently students will revert to prior ways of knowing even though they
have been taught differently in the science class. Often the ideas that a student has do not
come from formal education but may result from strongly held beliefs about how the
world works or because of a fragmented and unstable understanding of the concept
(McDermott, 1990). Because of the dissonance between new knowledge and prior
knowledge, time is needed for students to reflect on new information and to actively
incorporate it into his way of thinking (Hoover, 2005).

**Constructivist Strategies.** The constructivist approach to science teaching involves
strategies that aggressively engage the student in activities that will promote long term
learning and aid the student in substituting scientific thinking for prior misconceptions of
science. To promote this shift the instructor must insure that students clearly understand
their own ideas, that they see the problems with their way of thinking and that the
scientific way of thinking about the issues will work better. Teaching strategies that
promote these consequences include following the National Science Education Standards,
using cooperative learning, using discrepant events, providing chances for prediction and
in depth discussion and using assessment that is framed by constructivism (Hoover,
2005). Additionally Hoover feels that lab activities that most effectively address
misconceptions and build on student learning are those labs in which the students have
not discussed the results, labs that occur before the lecture or discussion, open-ended labs
in which students construct their own data tables, and labs in which the students invent
the procedure. In implementing a constructivist teaching style, the teacher must no longer
Shapiro (1994) neatly summarized the constructivist view of knowledge in science into the five categories of reality, knowledge, purpose of knowledge, role of the learner and role of the teacher. In considering the role of the learner, George Kelly’s personal construct theory indicates that changes in a student are not the result of external forces but are the result of how the person views the situation (Shapiro, 1994). Because of prior knowledge, students may need to be taught in different ways to understand the same concept (Hoover, 2005). Based on this approach, the researcher uses conversation with the individual as the basis for observation in an attempt to understand the learner’s thinking and includes questions that allow the participant to provide a self-characterization and to create learning situations that will work for all students.

In considering the role of the teacher, Colburn (2000) suggests that the teacher’s role is to ascertain and help clear up misconceptions. A teacher’s role is to use lecture, questioning and demonstrations in a way that involves students in active and metacognitive thinking, and to use assessments that go beyond traditional testing.

One issue that educators frequently show concern over is that what the students actually choose to learn may not be what the teacher is trying to convey. These issues are addressed by Bencze (2000) who says that teachers may negotiate the constructivist-learning situation for students by maligning student pre-instructional conceptions, subversively directing student activities by limiting materials or procedures and controlling possible conclusions. Although this does not fit the true constructivist model,
it does appear to be advantageous for some situations. It seems that an occasional use of manipulation by the teacher may be necessary in order to direct a student’s learning toward the goals of science literacy as set forth by the AAAS and the NRS (American Association for the Advancement of Science, 1993; National Research Council, 1996).

**Criticisms of Constructivism.** Critics of constructivism frequently cite the inefficiency of constructivist teaching as a fault of this learning theory. They argue that the time students spent on constructing their own knowledge might have been better spent by the teacher simply conveying the knowledge (Kickbusch, 1996). He argues that the breadth of coverage of material in the typical classroom robs the students of the opportunity to develop personal understanding achieved through depth of coverage. If indeed, one feels that breadth is necessary, perhaps judicious examination of the curriculum will allow the selection of the most important concepts that warrant depth of coverage through constructivist strategies while the lesser concepts can be relegated to the behaviorist strategies that favor recall.

Perhaps the most difficult thing facing constructivism in the classroom is that it is diametrically opposed to how the teachers in the classroom have been taught. Traditionally, education in America has been based on Skinner’s ideas of behaviorism and as such teachers must now redefine the roles of teacher and learner in order to meet the demands of today’s classroom (Kickbusch, 1996). According to old educational standards, a competent student relied on memory and the ability to do specific tasks such as mathematical computations or cookbook style laboratories while teachers were expected to cover the text and prepare students for standardized tests. Kickbusch rightly suggests that a curriculum based on constructivist ideas will not allow a teacher to cover
the test but will allow a student to become builders of knowledge rather than a product of his school.

Meaningful Learning and Conceptual Understanding

The human constructivist model of science teaching and learning offers an alternative to the hunches, guesses and folklore that have guided the science education profession (Mintzes and Wandersee, 1998). In constructing meaningful knowledge, human constructivists take a moderate position on the nature of science. They prefer to view science in a way that acknowledges an external and knowable world but depend on the intellectually demanding struggle to construct heuristically powerful explanations through extended periods of interaction with objects, events and other people (Mintzes & Wandersee, 1998). Since people are meaning-makers, education’s goal should be to construct shared meaning and the role of a well-prepared teacher is to intervene when necessary in order to facilitate this goal.

Meaningful Learning. Mintzes and Wandersee (1998) define meaningful learning as the learning which a learner integrates into his cognitive structure in a logical, self-defined manner that makes sense to him personally. For meaningful learning to occur the material must have possible meaning, the learner must be able to attach the new knowledge to related prior knowledge and the learner must be willing to voluntarily include the concepts in his knowledge framework. For this to occur learning activities must actively involve students in the learning process, require the use of metacognition, connect to real world situations and allow the student to explore the information in more than one way. As described in the concept map of Appendix E, metacognition actively
involves students and promotes meaningful learning by scaffolding new information to prior knowledge.

Even though meaningful learning is more likely to occur when students are offered this depth of knowledge, this means of teaching is not as frequently used as one would wish. Teachers do not have the time or, sometimes, the knowledge needed to develop in-depth units that promote deep thinking and personal involvement of the students. Additionally, if the students do not feel connected to the unit or have a reason to study the unit, they will probably not expend the effort needed to get real value from the instruction.

**Conceptual Understanding.** For a student or any other person to make meaning of what they know, conceptual understanding is a must. McDermott (1990) feels that conceptual understanding of a concept includes the ability to perform a specific task such as the ability to apply a concept to a particular observation, the ability to recognize situations when the concept applies, and the ability to distinguish the concept from similar concepts. Conceptual understanding is also evident when the student can think of the concept theoretically, show relationships and show a hierarchy of the concept in relationship to other concepts.

Reif (1987) indicated that conceptual understanding required procedural knowledge to work with the concept, enough knowledge of the concept to allow inferences between knowledge, knowledge that fit into preexisting knowledge structures and a sufficient bank of previous knowledge to allow for interpretation of new knowledge. Additionally, Brown and Campione (1990) suggest that the learning environment should enhance conceptual understanding. They advocate a classroom
environment that allows for group problem solving, requires students to explain, elaborate or expand on knowledge and provides problems that may have more than one correct answer.

Strike and Posner (1982) emphasize that learning science is more than the acquiring facts. They equate learning science with the production of new scientific knowledge and contend that change in both learning science or producing new science knowledge is not an accumulation of new information but a transformation of the existing knowledge. Additionally, learning science and doing scientific research are similar in that both require a judgment of the validity of ideas on the basis of evidence and result in a change of mindset. To understand the conceptual change of learning, Renner and Marek (1989) equate learning to the development of new science. They suggest that new science is developed through working with and understanding the current views of science; there is a difference between normal and revolutionary science and that new scientific knowledge interacts with and changes the current views of science.

In considering this view, one is forced to remember that students come to class with prior knowledge and that any new thing they learn must be incorporated into what they already know. Brown & Campione (1990) argue that two faulty aspects of metacognitive knowledge are the knowledge that children possess about learning is inadequate so they are unable to self monitor their learning and that students may frequently overestimate their understanding thus exerting little effort to learn more thoroughly.

**Learning Style.** One aspect of learning that should be considered is that of learning style. Although this idea has been considered by others, David Kolb developed
the experiential learning theory which aptly describes the concept that students learn in
different ways. In his experiential learning theory he suggests that learning requires both
inputting information and processing information but that people have different
preferences on the order of these two processes (Kolb, 1984). He suggests that learning is
achieved when the learner undergoes four steps of learning that include concrete
experience, abstract conceptualization, reflective observation and active experimentation.
He postulates that people have different preferences on how they learn and can be
categorized into the four groups of divergers, assimilators, convergers and
accommodators, depending on their preferred means of learning. Little (2004) suggests
that these learning styles can be accommodated in the classroom by incorporating a
variety of instructional strategies that fit the needs of the specific learning style and might
include discovery learning, active participation, lecture, providing examples,
incorporating time for student reflection, demonstrations, laboratory explorations,
interactive instruction and computer assisted instruction.

Motivation. Motivation has long been considered a means of improving student
participation and concern for learning. If a student has no interest in learning, learning
will not occur, either by rote or in a meaningful way. In one such instance, Lubben et al.
(1996) found that students displayed more positive attitudes toward lessons when they
were allowed to work on personally useful applications, could own the activity by
contributing their expertise and knowledge and could discuss contentious issues.
Motivation and student enjoyment also increase when instruction involves everyday
contexts in science teaching (Campbell, et. al 1994). These authors indicated that
improved responsiveness of students could result through contextualizing and improving
relevance. The work of Peacock (1995) showed that contextualization improves access to knowledge and that contextualization is particularly appropriate for curriculum regionalization. Hence, one might conclude that motivation could be improved by choosing a topic that is localized and part of the area’s economy.

**Brain Research and Learning**

As depicted in the concept map of Appendix F, the brain is the seat of learning and is the subject of much research. How the brain works has been a mystery since antiquity and as a consequence, brain research has been conducted for centuries. Man’s fascination with his own brain is reflected in illustrations such as those of Lorenz Fries in 1517, Johannes Dryander, Sir Charles Bell and Santiago Ramon y Cahal (Robin, 1993). This fascination is especially evident in the work of the French anatomist, Paul Broca who was the first to establish that cognitive traits and functions are processed in particular regions of the brain (Shreeve, 2005). With new understandings of brain function, neurologists and educational psychologists are beginning to connect learning and brain function more precisely than ever before. Although we now know that definite regions of the brain have specific functions, it is becoming apparent that the activity of brain during mental activity may involve a complicated network of interacting regions of the brain. Thus, if one wishes to understand cognition, one must first understand the brain.

Many of the first and best ideas on cognitive function are the results of studies of the damaged brains of patients (Shreeve, 2005). Among these efforts are those made by the American neurosurgeon Wilder Penfield. Through the use of electrical stimuli on the brains of epileptic patients, he determined that one side of the body was actually
controlled by the opposing side of the brain cortex. Since Penfield’s research, the field of brain research has expanded greatly so that a collection of over 50,000 brain images is now available at UCLA’s Laboratory of Neuro Imaging for exploring the function of the human brain. Brain research has been greatly improved through improved technologies for brain imaging. These include electronencephalograph, functional magnetic resonance imaging (fMRI) and optical imaging of intrinsic signals (OIS) (Shreeve, 2005).

As brain research progresses, an understanding of how learning occurs slowly becomes clearer. Zull (2002) suggests that learning involves changing data into knowing and that the best learning occurs when there is good communication between the temporal cortex and the prefrontal cortex. He states that learning entails the transformation from past to future, from outside ourselves to inside ourselves and from transforming the power of learning from others to ourselves. He also states that the back integrative cortex is responsible for memory, understanding language and emotions whereas the front integrative cortex is responsible for choice, decisions, emotions related to action, responsibility, prediction and creativity.

**Visualization**

One aspect of the brain which teachers should take advantage of is its almost unlimited capability to store images. Memory experiments show that people can recall hundreds of pictures that they have only seen for a few seconds (Zull, 2002). The concept map of visualization (Appendix G) shows how visual images can be used as a pedagogical tool to help students understand connections to enhance recall. A visual depiction of an idea is often a very effective means of helping students understand concept. Students often find illustrations and diagrams more appealing than reading
material and can learn from making graphics themselves. Biology teachers have frequently employed sketches of organisms as a means of learning anatomy and for comparison of species. Herron (1990) suggested that the ability to visualize the problem may enhance problem solving by providing a visible representation of the situation and providing practical information about what needs to be done, thus indicating that the ability to associate images and concepts improved with practice. Consequently, there are multiple reasons for using visualization as a teaching tool. An understanding of why visual tools are effective and how to select effective images will help develop a better sense of when to use visual tools in the classroom. Zull (2002) rightly recommends that when using images or other visualizations as a pedagogical device one should consider what the best example is. The image should be as close to the real experience as possible and the most important parts should be indicated.

In visualizing an object the brain breaks down the image by color, form and orientation in the visual cortex, then the information is sent to temporal lobe to analyze and interpret the image. The hippocampus is involved with memory. Evidence shows that the hippocampus can grow new cells and that the rear portion of the hippocampus is normally larger in persons with a large spatial memory (Shreeve, 2005).

Solso (2003) describes vision as the cognitive interpretation of signals from the brain as information from the object flows through the eye, through the visual cortex and finally the associative cortex. This process is called natiristic perception and is essentially the same for all humans with normal vision. However, the way we interpret an image is called directed perception and depends on the interactions of the image with prior memories, personal history, knowledge and preference and may be different for a novice.
learner and an expert. This is similar to what Kleinman, Griffin, and Kerner (1987) found when comparing novice and expert chemists. They found that the number of and level of abstraction of images in chemistry increased with experience when evaluating the use of images by undergraduate chemistry students and professors. Similarly Zull (2002) states that visual tools in teaching may promote learning because visuals allow the teacher to point out details and important differences that are not apparent to the novice but obvious to the expert.

Another aspect of incorporating visuals such as graphics in the classroom is the large amount of data available to the reader that is not available in written texts. Tufte (2001) suggested that graphics can organize large data sets, make comparisons and tell a story. The effectiveness of graphics can be enhanced by using tools such as direct labels, encodings as seen in color scales and self-representing scales by including of objects of known size in the graphic to show quantities (Tufte, 1997).

Inquiry

Anxiety for the quality of science education has been an ongoing concern for the scientific community and the public since Sputnik was launched by the Russians and Americans began to realize that their nation was losing its prestige as a leader in scientific innovation and discovery. Even then, there were members of both the science community and the education community that felt that the best way to improve science education lay in a move to incorporate a more scientist like component in science classes (American Association for the Advancement of Science, 1990).

The concern for quality science education continued through the eighties, In 1981, the National Commission on Excellence in Education was established and given several
missions including that of assessing the quality of education in the United States at all levels as compared to other nations, and defining the specific problems that needed to be overcome to achieve excellence in education (National Commission on Excellence in Education, 1984). They concluded that our nation was at risk as evidenced by the degree of illiteracy, low achievement on standardized tests such as the ACT, and a lack of higher order thinking skills in 17-year-old students. Specifically for science they noted declining achievement scores during the seventies. The commission felt that maintaining a strong international economy would require a strong education in the sciences, technology and mathematics. However they found that there was a shortage of science and mathematics teachers and that the quality of science education was hindered by unqualified science teachers and inadequate training for in-service teachers. Additionally they cited a need for improved sequencing of mathematics and science courses.

Now, as then, many advocate the promotion of inquiry as a means of encouraging scientist like thinking; yet high school and college science has traditionally been and is still taught as a predominantly lecture course with little student activity while elementary science and middle school science may be nonexistent or a very minor portion of the curriculum. This results in a science curriculum which students find uninteresting and trivial, that has no relevance to real life, and that does not promote problem solving, communication or thinking skills (National Research Council, 2000). Currently the science teachers’ dilemma of including inquiry in the curriculum is multidimensional. Many teachers cite time as a limiting factor that prevents the inclusion of inquiry-based science instruction, while others cite a sense of inadequacy in science preparation or inquiry pedagogy for failure to include inquiry in the curriculum, and still others cite a
concern for lack of classroom discipline as reasons for inquiry exclusion. To make inquiry instruction an active component of the science curriculum, teachers must become familiar with the history of inquiry in the classroom, what inquiry is, how it can be incorporated in the classroom and how it can promote higher order thinking skills.

**History of Inquiry.** While the movement to include inquiry in the science curriculum is a topic of much discussion in current science education research, it is not a new topic. As shown in Appendix H, components of inquiry have been advocated for years and include some of the most prominent educators such as Dewey, Piaget, Bruner, and Schwab. The science used in the Laboratory School of the University of Chicago in the early 1900’s under the leadership of John Dewey actually mirrors the modern ideas of inquiry style learning (Dewey, 1990). Dewey says that students who develop their own questions will have a “true, reflective attention” and will actively seek material and use the skills of “judging, reasoning and deliberation to answer the questions” (148). Similarly he states that “science is largely of an experimental nature” (170), that “learning is active” (187), and that the student “determines both the quality and quantity of learning” (187) (Dewey, 1990). This corresponds well with the NRC’s definition of inquiry as the activities in which students engage in order to develop knowledge and understanding of scientific ideas and to see how scientists study and explain the natural world (National Research Council, 2000). The activities that define inquiry involve a wide range of activities such as making observations, posing questions, probing books and other information sources, gathering and manipulating data, and constructing and communicating answers to questions.
The educational psychologist, Robert Gagne (1963) spoke of inquiry as one of the most essential elements of science education and concluded that students who had mastered scientific inquiry would be able to adapt the procedures of the method to any new problem he faced. Using Bruner’s work, Gagne described inquiry as a guide to discovery and felt that practice in inquiry would result in improved ability to conduct inquiry research. He also inferred that Schwab developed specific ways in which to incorporate inquiry practice in the classroom and felt that such practices allowed students opportunity to use inductive reasoning and make and test hypotheses. Gagne additionally indicated that use of inquiry in the classroom afforded students the opportunity to develop the ability to generalize principles from their inquiries as well as the ability to discriminate the value of different hypotheses.

Specific illustrations of inquiry in the curriculum were published as early as 1957 when the Manufacturing Chemists’ Association supported the planning for open-ended chemistry experiments (Charen, 1963). In measuring the effectiveness of these commercially available experiments, Charen found that although the open-ended experiments were particularly effective in promoting student motivation, it was difficult to assess their effectiveness on critical thinking and teachers needed more time to prepare for the inquiry type experiments.

During the mid sixties, researchers in the state of Michigan examined inquiry as a possible means of teaching junior high science as an interdisciplinary science course that could bridge the gap between the generalized science of the elementary schools and the specific science courses of high school (VanDeventer, 1967). In an effort to improve the science education at the middle school level the Michigan Science Curriculum
Committee Junior High School Project developed thirteen instructional units that had fifty-five open-ended laboratory experiences. VanDeventer correctly emphasized the fact that the open-ended laboratories were only a part of the inquiry process and that science itself is not just facts but rather a way of learning through investigation. Inquiries developed by the Michigan group focused on categorizing the questions asked by (1) those easily answered through experience or available materials, (2) those that could be answered with considerable investigation and thought, (3) those that neither teacher nor student could answer, and (4) those that probably could not be answered with the current pool of knowledge.

Impact of Inquiry on Science Literacy. Two of the leading organizations in the area of science education, the National Research Council (NRC) and the American Association for the Advancement of Science (AAAS) include inquiry as an important component of science literacy. The NRC (1996) defines inquiry as the activities in which students engage in order to develop knowledge and understanding of scientific ideas and to see how scientists study and explain the natural world. The activities that define inquiry involve a wide range of activities such as making observations, posing questions, probing books and other information sources, gathering and manipulating data, and constructing and communicating answers to questions. Similarly the AAAS (1993) describes it as a “subtle and demanding process” in which the students participate in investigations that approach the work of real scientists and is orchestrated and conducted by the students rather than the teacher.

Even though the idea that inquiry is very similar to what scientists do, misconceptions of what teachers consider inquiry abound. Llewellyn (2002) listed the
following commonly cited myths of inquiry-based learning: (1) Inquiry is simply hands on activities, (2) inquiry is simply the scientific method, (3) students engaged in inquiry are beyond the teacher’s control, (4) inquiry requires the teacher to ask the students a lot of questions, (5) inquiry requires the teacher to have all the answers, (6) inquiry is for lower grades only, (6) inquiry cannot be evaluated, (7) inquiry is simply the latest fad in science education, (8) inquiry has no substance, and (9) inquiry is for high achieving students only. Although these circumstances may exist when inquiry is not thoroughly understood or properly implemented, correctly presented inquiry lessons can promote higher order thinking and meaningful learning and will allow the teacher to learn with the students when encountering unfamiliar information.

Simple means to move instruction to a more inquiry based instruction include asking questions in a more general format so that answers will be more than one word answers, asking students for possible experiments rather than summaries of labs and having students create their own graphs rather than filling in a template. A particular instructional method that is based on an inquiry type of approach that can improve science literacy as advocated by AAAS and NRC was developed by Roger Bybee and is known as the 5E learning cycle model (Bybee, 1997).

Roger Bybee’s 5E Learning Cycle. Roger Bybee’s 5E learning cycle is a particularly effective means of making classroom practices more in line with the National Science Education Standards (Colburn & Clough, 1997). This instructional method is based on an inquiry type of approach and can improve science literacy as advocated by AAAS and NRC (Bybee, 1997). This model provides instructors with all the elements of scientific inquiry in a simple blueprint that can be adapted to a number of investigations.
and promotes active student learning (NRC, 2000). The steps of the instructional strategy include the components of engage, explore, explain, elaborate and evaluate. The engage stage is an activity that catches the students’ attention in a way that gets them thinking about the concept in question, engages prior knowledge and allows the teacher to recognize any misconceptions. In the explore and explain phases, students are encouraged to participate in the scientist-like activities of designing, completing and reporting experiments. Participation in the elaborate phase allows students to extend their understanding by applying their new knowledge in new ways. In the evaluate phase, the teacher formally assesses students on achievement through determining the students’ ability to apply the new knowledge to new situations or to interpret information from the activity in a new way.

**Assessment**

Today, the words evaluation and assessment are often used interchangeably, though many perceive evaluation to refer to the appraisal of all components of an educational system and assessment as an appraisal of student performance. In modern classrooms, these can come in many forms of student assessments such as formal or informal, formative or summative, normative or criterion referenced, and traditional or performance based, and alternative. Concern for modern day assessment and evaluation has been the topic of concern for a number of educators including Mintzes, Wandersee and Novak who state “as we view it, poor assessment practices in the elementary and secondary schools (and in colleges and universities) are clearly among the most significant impediments to understanding and conceptual change” (Mintzes, Wandersee & Novak, 2000, p. iv). These authors also say that “High-quality assessment can facilitate
learning; but unfortunately, poor assessment can deter or prevent high-quality learning and may reward performance that is deleterious to the learner in the long run” (Mintzes, Wandersee & Novak, 2000, p 1). Hodson very succinctly expresses a concern for evaluation when he states:

First, students are often unwilling to change their views of learning; especially if their current strategies are successful (in whatever terms the school recognizes success). Second, if there is no immediate pay-off from the school system, students will continue with existing, familiar methods - unless there is a powerful alternative motivation. Clearly, this has implications for assessment and evaluation practices. It is worth noting that portfolio-based assessment creates opportunities for engagement in more authentic learning tasks and provides a valuable resource for metalearning. Student portfolios include tangible evidence of conceptual changes that have occurred and reinforce recollections of changes undergone, thereby providing a powerful stimulus for reflective thought (Hodson, 1998, p. 43).

As described in the concept map of Appendix I, issues of assessment have long been a matter of concern for educators and can entail much more than the traditional pen and paper test. One of the premiere educational researchers in the area of assessment was Ralph W. Tyler. In Basic Principles of Curriculum and Instruction Ralph W. Tyler (1949) created a primer for curriculum development that became known as the Tyler Rationale. The book originally served as the syllabus for a course that he taught at the University of Chicago in the 1950s and is still printed in a multitude of languages and in many countries. When the events of the forties brought many more children into the classroom, his book laid the foundation for the standardization of American education. Tyler included evaluation as one of the four crucial steps in developing a curriculum and created many assessment practices that are still prevalent today. Today, the No Child Left Behind (NCLB) legislation and issues of teacher accountability have resulted in an overabundance of testing. Students are inundated with state criterion referenced tests and norm referenced tests in addition to the normal classroom testing and evaluation.
According to Wraga, “the national reform movements typically embrace standardized test scores as the primary measure of school effectiveness” (Wraga, 1994, p. 72).

**Tyler.** Tyler’s *Basic Principles of Curriculum and Instruction* was republished in 1969 as a paperback edition and remains in print today. The book is appealing in its simple format based on four organizing questions. Tyler (1949) suggested that the four questions of purpose, educational experiences, organization of these experiences, and evaluation of the attainment of these purposes should direct curriculum development. Though the Eight Year Study was commenced to help develop high schools that better prepared students for subsequent college study, one of the most important results of the study was that Ralph Tyler became associated with the evaluation and assessment of educational programs. Tyler actively participated in educational assessment for a period of over 70 years (Horowitz, 1995).

The term evaluation was actually coined by Tyler when working with The Ohio State University. In an interview with Jeri Ridings Nowakowski in 1983, Tyler says that he first suggested using the word evaluation “to refer to testing what students were actually learning” since “the term ‘test’ was usually interpreted as a collection of memory items” (Nowakowski, 1983, p. 25). According to Horowitz (1995), Tyler states that the purpose of evaluation is to assess the work of individual students and encourage them to study, identify learning difficulties of students in order to guide lesson and curriculum planning, and determine the effectiveness of a curriculum. The purpose of evaluation is also to determine the progress of populations so that the general public can be aware of the status of schools in order to make informed decisions on public policy. A modern day definition of assessment offered by Olson (2005) is that it should measure individual
achievement growth in reference to state and local standards that can be used to modify curriculum and should be readily and quickly available. Like Tyler, Olson idealistically sees assessment as a tool to guide the instruction of individual students and the effectiveness of an individual teacher’s instructional strategies.

Tyler suggests that evaluation actually begins with selecting and organizing learning experiences based on educational psychology and experience and that this type of assessment may be referred to as intermediate or preliminary forms of evaluation (Tyler, 1949). These neatly correspond to today’s ideas of formative assessment. However, one distinction of Tyler’s interpretation of evaluation and today’s is that Tyler suggests that education is not only for the evaluation of the student but is important for the evaluation of the curriculum and whether the students have achieved what the educators had intended (Tyler, 1949). Because actual teaching procedures are highly variable with different students in different situations by different teachers, Tyler cautions that some form of evaluation must be employed to insure that the intended outcome of instruction has been successfully achieved. Tyler defines evaluation as “a process for finding out how far the learning experiences as developed and organized are actually producing the desired results” (Tyler, 1949, p. 105). He suggests that to improve instruction there must be an “evaluation of every important step” and that “definite evidence of what students have learned and how much they retain becomes a necessity” (Tyler, 1989, p. 9).

The intent of evaluation is to help identify weaknesses and strengths of the lesson plans, “check the validity of the basic hypotheses upon which the instructional program has been organized and developed,” and determine the effectiveness of the instructional
program and where the program needs improvement (Tyler, 1949, p.105). He adds that two important aspects of evaluation are that (1) the evaluation should assess the change of behavior of the student and (2) since this evaluation is based on a change in behavior, the evaluation must occur more than once. This corresponds to today’s pre- and posttest used in many educational studies.

Although most often this is interpreted as pen and paper test, Tyler advises that not all types of behavior can be evaluated with traditional tests. Hence, he recommends use of observations to determine social adjustment, interviews to assess changes in attitude, and questionnaires to provide evidence of change in interests and appreciations. Collections of student products can serve as evidence of change and may include writing samples, drawings, and student material products (Tyler, 1949). It is rather disconcerting that the individualism suggested in Tyler’s rationale has been largely ignored in much of today’s evaluation forms which are predominantly multiple choice and largely antiseptic.

According to Tyler, the procedure for evaluation or assessment should begin with the objectives of the program and the content of the assessment tool should be appropriate for the objectives chosen. Tyler recommends that “the appraisal of the human behavior should be an analytic one rather than a single score summary” with an eye for improvement by including components that can provide evidence about weaknesses and strengths of both students and teachers and the program of study. Another aspect of selecting or creating evaluation is whether the instrument will provide the same scores if evaluated by another rater. Additionally it should be objective, reliable and valid, defined by Tyler as the “degree to which an evaluation device actually provides evidence of the
behavior desired” (Tyler, 1949. p.119). It is assured by directly taking a sample of the behavior being tested or by correlating the instrument to a test known to be valid.

Results of evaluation should be used to adjust curriculum and explain patterns of weaknesses and strengths. Tyler says “that curriculum planning is a continuous process” (p. 123) and “in this kind of continuing cycle, it is possible for the curriculum and instructional program to be continuously improved over the years” (Tyler, 1949, p. 123). However, he states, “unless the evaluation procedure closely parallels the educational objectives of the curriculum, the evaluation procedure may become the focus of the students’ attention and even of the teachers’ attention rather than the curriculum objectives set up” (Tyler, 1949. p.124). This quickly brings to mind one consequence of President Bush’s No Child Left Behind Act of 2001.

No Child Left Behind. George W. Bush set education as his number one priority of his presidential administration and in January 2001 sent the No Child Left Behind Plan to Congress. This plan was to establish comprehensive education reform for the United States (U.S. Department of Education, 2005). In an attempt to increase accountability, each state is required to monitor what students are learning in reading and mathematics in grades three to eight. This is monitored through tests that are administered to every child every year. Schools are required to report these findings annually in report cards that provide data on school performance and on statewide progress. Results are available to all citizens and will provide parents with an idea of the quality of their child’s school, how well qualified the teachers are, and how their child has progressed. As a result, states have increased the rate of standardized testing and in many cases have established testing standards.
In a critique of the No Child Left Behind Act of 2001, Fritzberg (2003) suggests that the implementation of the act has “hardly been smooth.” A justifiable intent of the NCLB is that evaluation should be used to insure that all sub-groups within a school are performing adequately and in fact has identified that weakness in thirty-three states (Fritzberg, 2003). One specific concern is that the standard grade-level tests are inappropriate for many disabled students or students with limited English-proficiency (LEP) even though literature, including Tyler’s rationale, suggests that evaluation should be individualized (Tyler, 1949). Fortunately, changes in testing requirements for these students have been initiated and should ease the burden.

Another and more serious critique of NCLB is that the Adequate Yearly Progress (AYP) is progressive with the unrealistic ultimate goal of having all students obtaining a perfect 100% by the school year 2013-2014. Although we all want students to perform to their maximum capability, it is extremely unrealistic to expect perfection from one student, let alone all.

However, Fritzberg’s largest criticism is whether children of every community are afforded the opportunity to achieve the set standards. His doubts stem largely from the fact that per student fundings are allowed to vary greatly from district to district. Since testing procedures and the tests themselves are created by state officials, the question of whose knowledge is honored is an issue. If chosen at the state level, little opportunity exists to adapt the curriculum to the needs of the individual child, school or even district.

The concern for the effect of high stakes testing, though now connected to NCLB, is not new. Wraga seems to have the right idea when he suggests that “high-stakes tests exert a less than salutary effect on curriculum, teaching and learning” (8) and that “the
resulting low-level instruction is prevalent especially with marginal students and leads to increased low-level instruction for many urban and rural students” (Wraga, 1999, p. 9). Based on the TIMSS and NAEP reports, there is evidence that the educational quality of American students is not top notch, yet past records indicate that more testing will not solve the problem (U.S. Department of Education, 1999) and (National Center for Education Statistics, 2005).

Criticisms of the Tyler Rationale. Apple (2004) likened the Tyler Rationale to systems management in terms of evaluation in that both assume that the success of a system can be judged by how well the outcome satisfies the purpose. One shortcoming, he feels, of both systems is that “in the quest for orderliness, the political process by which often competing visions of purposes deal with each other and come to some sort of understanding is virtually ignored” (Apple, 2004, p. 105). Similarly, he proposes that the Tyler Rationale in curriculum is an administrative document that does not deal with the reality of schools.

An apparent shortcoming of Tyler’s document is that its simplicity has resulted in many curriculum developers using the format as a basic recipe to deliver a rather generic curriculum that has not considered the individual or the specific community in which it will be used. Interviews with Tyler, however, indicate instead that the intent of Tyler’s rationale was very much student oriented. He tells Meek that “you have to work with the child to see what the child’s needs are,” Nowakowski that “one must consider the learners what they have already learned, what their needs are and what their interests are,” and Horowitz that “the teacher wants to be guided by building on what the student already knows or does or feels” (Meek, 1993 p. 85; Nowakowski, 1983; p. 27 & Horowitz, 1995;
p. 3). In an interview with Meek (1993), Tyler said that “schools that are effective have to consider their students’ needs and work with them” and that to improve schools one needs to start with the problem (Meek, 1993, p.85). Similarly, in an interview with Nowakowski, Tyler suggests that “one must consider the learners, what they have already learned, what their needs are and what their interests are, and build on them; one must also consider the potential value to students of each subject” (Nowakowski, 1993, p.27).

Though Tyler’s Rationale was intended as a blueprint to guide curriculum development with an emphasis on the student and on the particular community, this is not how it has been interpreted. Evaluation based on Tyler’s rationale should be multifaceted with many components and should be custom fit to the program, teacher and student. According to Tyler, evaluation should be used as a tool that can lead to improvements in student and teacher performance and can be used to direct changes in curriculum. He sees it as a tool for the educator rather than the ultimate goal of education. This contrasts sharply with NCLB which has developed a generic one-dimensional evaluation plan in which the evaluation drives the curriculum rather than the curriculum driving the evaluation.

In closely examining the work of Tyler, the basic plan for developing a curriculum and an evaluation of that curriculum suggests that you carefully consider the student, where he comes from and what his interests are. In today’s reality, however, state and federal mandates in the form of No Child Left Behind accountability issues stifle the individuality of curriculum and result in a generic plan that only suits the “average” person with teachers teaching to a test and students learning for the test. Consequently, one needs to examine alternative forms of assessment that can provide a means of
individualizing instruction and assessment that promotes the student’s need to be in control of his own learning.

**Current Uses of Assessment.** Assessment is an integral component of instruction and can be used in both a formative and an evaluative sense. Assessment, according to Kickbusch (1996), is a necessary component of instruction and should include known criteria. Smith, 1993 states that regular and frequent evaluation and assessment activities are accounts of intellectual development that provide an observable way to display knowledge and growth. Depending on the purpose, assessment has traditionally been in the form of paper and pencil tests that may be either criterion referenced or norm referenced and presented in either a casual or formal setting. Frequently, the test is an end in itself and is not used to direct instruction.

However, assessment should not be limited to paper and pencil tests but should include products and activities that reflect class activities. In addressing environmental education specifically, Tal (2005) suggested that assessment should address inquiry learning, critical thinking, awareness of environmental problems, performance and participation in environmental activities. With the issue of accountability becoming increasingly more important through governmental legislation such as the No Child Left Behind Act, traditional tests certainly must remain a component of evaluation. Yet, traditional paper and pencil tests are not always used to guide instruction nor will they adequately evaluate student achievement. For teachers concerned with helping their students achieve meaningful learning other means of assessment must be employed. In fact, when properly used, alternative assessments can facilitate meaningful learning through guiding instruction, recognizing student misconceptions, and actively engaging
the students in recognizing their own learning (Novak, Mintzes, & Wandersee, 2000). Accordingly, assessment activities employed in a constructivist classroom should be those that provide students with opportunities to actively connect new concepts with prior knowledge and can help the students order the new ideas in a way that is meaningful to them. Alternative assessments may include but are not limited to student projects, concept mapping, vee diagrams, structured interviews, observation rubrics, portfolios, and student writings. What they are and how they can be incorporated into a meaning-making curriculum is an important aspect of science instruction.

**Concept Maps.** As shown in the concept map of Appendix J, concept mapping can serve to help students organize thoughts, connect to prior knowledge and assess student achievement. These maps are metagraphic representations of knowledge and can be a powerful means of allowing students to monitor their own thinking or to evaluate student progress (Wandersee, 2000). They are two-dimensional and arranged in hierarchical fashion with a set of 10 to 14 concepts joined by linking phrases. This author describes concept maps as maps of cognition and warns that both concept maps and cartographic maps are only as good as the quality and quantity of the data supplied. Concept maps are influenced by prior knowledge, can be an indicator of change or growth and provide an excellent means of integrating and summarizing knowledge. Evaluation of student maps can be achieved through the criteria of levels of hierarchy, validity of propositions, and appropriate use of cross links and examples (Edmondson, 2000).

**Self Reports.** In order to promote meaningful learning, students must be actively involved in the learning process. This includes a need for the students to assess their own
work. Based on fifteen years of experience, Tamir (1999) presented two forms of self-assessment instruments. Both instruments have been evaluated for validity and reliability and can serve as a pre-test in order to detect any misconceptions. The Self-Report Knowledge Inventory (SRKI) is designed by compiling a list of the concepts the students are expected to master. Students are asked to evaluate their knowledge of the concept on a five point anchored scale. The Opportunity To Learn Inventory (OTLI) consists of a list similar to the SRKI list but students simply tell whether or not they have studied the concept. When the SRKI and OTLI were administered to 116 students in an introductory course in college biology, internal consistency coefficients were above 0.9 for concepts and above 0.8 for skills when evaluating the students ability to recognize concepts they had learned in high school biology versus concepts they had not yet been taught. Similar results were determined in 106 high school biology students when comparing students who had specialized in biology with those who had not. Other evidence supporting the validity of the self-assessment scores were positive correlations (an average of 0.3) between the SRKI and OTLI scores at the beginning of the year to course achievement scores and attitudes at the end of the year. Use of SRKI and OTLI instruments may be an effective means of evaluating student understanding of environmental change.

**Roundhouse Diagrams.** In an effort to determine strategies that effectively promote meaningful learning, Ward and Wandersee (2002) evaluated Roundhouse diagram construction as a means of improving the understanding of middle school students’ understanding of abstract science concepts. As conceived by Wandersee, a roundhouse diagram contains a center circle that serves as a conceptual hub for the diagram’s theme and seven outer sectors in which the student uses symbols to
sequentially depict the seven main concepts that relate to the theme. The diagram serves as a metalearning tool that allows the student to graphically organize the information in a personally meaningful way. For the 19 middle school students involved in the evaluation of Roundhouse diagrams, quantitative data indicated that all students mastered the skills of creating Roundhouse diagrams. A correlation \((r = 0.560)\) was found between the student academic progress and mastery of diagram technique. Qualitative evaluation of one student indicated tremendous growth from a nonparticipating, tentative student with poor grades to a student with higher self-esteem and improved higher order cognitive skills.

**Vee Diagrams.** Vee diagrams were developed by D. B. Gowin as a heuristic to help students envision laboratory work but have also been used at all academic levels to direct and focus research efforts or plan instructional materials (Novak & Gowin, 1984). A Vee diagram divides a student’s thinking into the conceptual, the methodological, the focus question and the event. The conceptual component provides a place for relevant theories, concepts and principles while the methodological component provides a place for the student’s knowledge and value claims, transformations and records. One unique value of the Vee diagram is that it forces the student to connect theory and practice thus effectively making him aware of the essence of the activity. Another value of the Vee diagram is that because the vee points from the focus question to the main event of the activity, students are more likely to stay focused on the intended purpose of the activity. Assessment of Vee diagrams may be successfully achieved by evaluating the four components for accuracy, completeness and quality (Mintzes & Novak, 2000).
**Observations.** Since observation is a key activity of scientists, students should develop the ability to observe and record phenomenon. Observation competency should include the ability to observe well, to report observations well and to accurately assess the validity of the observation (Trowbridge & Wandersee, 2000). Student observation can be used as a form of assessment by developing a rubric for that evaluates the student’s ability to perform these three criteria.

**Writing.** By incorporating writing into student activity, the instructor provides a means of promoting meaningful learning as well as an assessment tool for evaluating student performance. Writing samples of the student can take the form of narrative, lab report, or can be included in a portfolio (Champagne & Kouba, 2000). Portfolios might include reports of student research, scientific analyses of social issues, in depth papers of fundamental science principles, journal reflections, graphics of scientific knowledge, concept maps and vee diagrams (Vitale & Romance, 2000).

**Environmental Issues**

Although environmental concern dates back to 1798 when Thomas Mathers expressed a concern for enough cropland to feed the world, the modern movement to protect our environment was launched when Rachel Carson published *Silent Spring* in 1962 (Pompe & Rinehart, 2002). Since that time the most pressing environmental issues have become approaching limits on food and water, loss of species, polluted air, polluted water, global warming, shrinking forest and spreading desert. An overview of current environmental issues is given in the concept map in Appendix K. According to the Environmental Literacy Council (2002) when considering the impact of humans on the Earth, environmental scientists look at these issues in terms of the four major subsystems
of air, oceans, land, and the biosphere. These scientists concentrate on the
interconnections of the four subsystems by examining physical and chemical processes
and how energy and matter cycles and flows through and between the four.

The issue of global warming is the topic of discussion for many
environmentalists. There are indications that the temperature of the Earth has increased
one degree over the last century (United States Environmental Protection Agency, 2000).
In a National Academy report on climate change, Staudt, Huddleston & Rudenstein
(2005) advise that surface temperatures have warmed in the last century as evidenced by
changes in the oceans, in ecosystems and in ice cover. They predict that global surface
temperatures could rise as much as 1.4 to 5.8º C by 2100 as compared to the 1990 levels
resulting in sea levels that may rise any where from 0.1 m to 0.9 meters. These increased
temperatures may have both positive effects such as milder winters and longer growing
seasons and negative effects that may include lose of coastal lands, changes in arctic
landscape and ecosystems, shrinking ice coverage, higher sea-level, increased flooding
and more severe storms. These authors consider greenhouse gases, probably caused by
increased use of fossil fuels, to be at their highest level in at least 400,000 years and
consider greenhouses gases to be a major cause of global warming.

Though the current increase in global temperature is largely contributed to human
impact, there is evidence that the earth has experienced changes in climate in the past.
One example is the natural variations due to solar radiation. Lean (2001) describes solar
irradiance as a magnetic activity cycle of eleven years that changes the sun’s energy
output and corresponds to changes in the occurrence of sunspots, flares and coronal mass
ejections. These variations coincide with global temperature records, upper ocean
temperature records and surface temperature records for the last century. Lean (2001) estimates the solar effect to be between 0.3 to 0.8 degrees C.

Chronological Records of Environmental Conditions. As shown in the concept map of Appendix L, chronological records of the earth’s past have helped scientists compare past climatic changes to those that occur now in an effort to more effectively evaluate impact of man on the Earth’s current climate. Although evidence gleaned from records such as coral reef growth layers, glacial ice layers and tree ring growth patterns indicate that the Earth’s climate has fluctuated through the centuries, the temperature increase of the last century appears to be the result of human activity. In an effort to determine the consequences of the apparent global warming of the last century, scientists have resorted to analyzing past natural chronological records to determine if the current trend is a repetition of the past. Chronological archives used by Rahmstorf (2002) include ice core samples, deep sea sediment cores and coral samples which have been analyzed for components such as species, abundance of fossil plankton, trace metal ratios, and oxygen isotopes.

One means of assessing climate change over the last 260,000 years has been extrapolated from various sources of data that include ice core samples (Kotlytokov, 1996). Ice core samples have been taken from Greenland and the Antarctic from ice as thick as 3,000 meters. Since the annual rainfall barely reaches 23 mm, researchers have deduced that the ice core represents precipitation deposited for several hundred thousand years. These data have been used to compare the temperature conditions of the Holocene (10,000 years ago), the Valdai Ice Age (10,000 to 120,000 years ago) and the Dnieper (Riss) Ice Age (120,000 to 260,000 years ago). Kotlyakov suggests that studying the past
interglacial warm periods can give insight on episodes of global warming of the present age. These warm periods occurred in the Holocene Optimum time, the last Interglacial time and the Pliocene Optimum time. Kotlyakov proposes that when the average global temperature rises, high latitudes experience maximum warming. If the temperature rises by more than two degrees, precipitation in all latitudes would likely increase. He projects that global warming will shrink permafrost, increase the amount of methane in the atmosphere, increase glacial melting and raise ocean levels. These alterations in climate conditions can possibly result in changes in water quality and amount of soil moisture.

Another natural archive is the chronologies established by cross dating the tree ring growth patterns from a variety of trees taken across the globe. By extrapolating temperature effects on tree ring density since the 13th century, Malcolm Hughes, director of the University of Arizona Tree Ring Laboratory, determined that the increase in global temperatures that the Earth has experienced in the last 100 years is the greatest ever. Experts at this lab attribute the increasing temperatures of the earth in the 20th century to artificial greenhouse warming (Spivack, 1998). The greenhouse effect is caused by the carbon dioxide of the Earth’s atmosphere preventing heat from escaping into space when it is radiated from the Earth’s surface. These authors hypothesize that the dramatic increase in fossil fuel usage and the increase in carbon dioxide in the atmosphere are most likely the culprits for this change in global climatic temperature.

**Consequences of Human Activity on Environmental Quality.** The United States Environmental Protection Agency (2000) believe that amounts of carbon dioxide as well as the gases methane and nitrous oxide have increased dramatically in the atmosphere since the industrial revolution resulting in a greater ability of the atmosphere to retain
heat. The EPA estimates that 98% of the carbon dioxide emissions result from burning fossil fuels for industrial and consumer uses. Other activities contributing to the problem are agriculture, deforestation, landfills, and mining (EPA). In addition to a rise in global temperature, the EPA predicts that rising concentrations of these greenhouse gases may also cause greater evaporation in some areas and an increase in the average global precipitation. They expect soil moisture to decline in many regions, and intense rainstorms to occur more often. These may result in a rise in sea level of two feet along the coasts of the United States.

Steps to decrease greenhouse gases include personal, national and international choices such as driving less, regulating emissions and sharing energy technologies, producing electricity by alternative means, sequestering carbon dioxide from manufacturing plants and depositing it in the land or in the ocean, and finding alternative energy sources for automobiles (Staudt, Huddleston & Rudenstein, 2005).

Other threats to our air quality include ozone, particulate matter, carbon monoxide, nitrogen oxides, sulfur dioxide, and lead. Ozone is a gas composed of three oxygen molecules and at the ground level is a product of nitrogen oxides reacting with volatile organic compounds in the presence of sunshine. Ground level ozone can be hazardous to human health and agricultural crops and is a component of smog. It is particularly harmful to asthma sufferers. In the United States human activities cause roughly 90% of the nitrogen dioxide emissions which combine with volatile organic compounds to make ozone, the chief component of smog. Particulate matter (PM) are tiny particles of matter in the air. These particles can either be visible such as dust, smoke, dirt and soot or can be microscopic. They may come from industrial or
agricultural processes or from automobiles. They pose a serious threat to those with heart and lung conditions and can settle on the ground, affecting the chemical and nutrient balance of the environment (EPA, 2000). In North America, combustion of coal and oil for electric energy production accounts for approximately 80\% of the atmospheric sulfur dioxide, the major source of acid rain (Blatt, 2005). The resulting acid rain is responsible for fish kills in fresh water, damage to statues and buildings in polluted cities such as the Taj Mahal and the Parthenon and a visibility of only 15 miles compared to a 75 mile visibility of 50 years ago. Motor vehicles contribute greatly to air pollution through the production of carbon monoxide, nitrogen oxides and lead. However, Blatt cheerfully reminds us that catalytic converters on automobiles and the ban of the sale of leaded gas has decreased these pollutants in the United States.

Pompe and Rinehart (2002) justly cite the economic impact of caring for the environment as one of the main reasons that major global environmental issues are not easily solved. The economic involvement in environmental issues is most clearly evident in the matter of disappearing species. These authors point out that species are becoming extinct through the sacrificing of rainforest in Brazil for cropland and the hunting of rare species in Indonesia for money. Other economic impacts are apparent in the fishing industry when 13 of the 17 major ocean fisheries are over fished or when economic incentives such as $80,000 for a single bluefin tuna make it hard to release a tuna when caught.

**Environmental Education**

One important matter that should be addressed in science education is that students need to be aware of and understand the environmental changes that are occurring
both locally and globally. As shown in the concept map of Appendix M, students should particularly understand what environmental change is, how environmental change affects them globally and locally, what steps are being taken to maintain and improve environmental quality and what the students’ role is in acquiring and keeping the environment sound.

As a discipline, environmental education is relatively new with such courses having been introduced in the late 80’s and is often centered on the issues of air pollution, water and energy use (Ballantyne, Fien, & Packer, 2000). American environmental education has its roots in the works of George Perkins Marsh, Nathaniel Southgate Shaler and John Muir and was initially concerned with the preservation of natural resources (Marsden, 1997). However, the Tbilisi declaration was authored in October, 1977 in Tbilisi, Georgia (USSR) and established the first framework, principles and guidelines for environmental education (UNESCO-UNEP, 1978). They established that environmental education is the result of integrating different disciplines and educational experiences in order to better meet the needs of society. The Tbilisi declaration states that

“A basic aim of environmental education is to succeed in making individuals and communities understand the interaction of their biological, physical, social, economic, and cultural aspects, and acquire the knowledge, values, attitudes, and practical skills to participate in a responsible and effective way in anticipating and solving environmental problems, and in the management of the quality of the environment.”

The Tbilisi declaration recommends that environmental education should be closely linked with the real world by focusing its activities around environmental problems that are part of the immediate community. The goals of environmental education should consider the environment as a whole, to a lifelong process, be
interdisciplinary, examine major environmental issues, promote cooperation in the prevention and solution of environmental problems, help learners discover the symptoms and causes of environmental problems, recognize the complexity of environmental problems and teach these in a variety of learning environments with a variety of instructional tools (UNESCO-UNEP, 1978).

Ballantyne, Fien, and Packer (2000) suggest that the knowledge base of the child is frequently greater than that of the parent, which seems to be a natural outcome of the discipline. They also discuss the fact that environmental education programs include skills in monitoring environmental problems, approaches to solving environmental problems and new attitudes about environmental issues. They rightfully feel that providing the students with opportunities to monitor air or water pollution is one of the chief ways of influencing students to become environmentally aware and to develop an interest in improving the environment. Experiences such as tree planting, environmental cleaning activities and other nature activities were hands on activities that raised student awareness of environmental problems (Ballantyne, Fien, & Packer, 2000).

Guidelines for Environmental Education Programs. Niedermeyer (1992) established a checklist for evaluating environmental education programs. As the founder and president of the Educational Development Specialists, Niedermeyer feels that environmental education programs need better definitions of program objectives. To determine the programs which promise to be most suitable for a classroom, Niedermeyer suggests that the objectives be clearly stated, include environmentally responsible behaviors and cover a wide range of environmental problems and issues. Materials should have adequate lesson plans and ample opportunity for students to practice the
objectives and should appeal to both teacher and student. Similarly, Tal (2005) suggests that in helping students to become environmentally literate and active learners, a variety of teaching approaches such as classroom learning, outdoor activities, project-based learning, multiple resources, an awareness of controversial issues and community involvement should be used and would require an assortment of different assessment types. He deems that the objectives of environmental education should include posing questions and searching for and critiquing pertinent information. Additionally, Tal judges environmental education to be holistic in that it involves various subject matters and learning environments and has cognitive, affective and behavioral outcomes.

Another article that provides guidelines for environmental education was written by Ramsey, Hungerford and Volk (1992). In this article, these authors suggested that the curricular framework of environmental education should prepare students to be able to adapt to a rapidly changing technical world, to understand contemporary global issues and to develop skills to effectively improve and maintain the environment. Objective clusters suggested by these researchers and also recommended by the Tbilisi Declaration include awareness, knowledge, attitudes, skills and participation (Global Research Declaration, 2002).

A sound environmental education program should be action-oriented, continuous, experiential, future-oriented, globally oriented, holistic, interdisciplinary, issue-oriented and neutral. This coincides with Amemiya and Macer (1999) who suggest that the process of environmental education includes becoming aware of the environment, recognizing the relationship of humans to the environment, developing skills to solve environmental problems and developing an attitude to participate in environmental
conservation. This is reiterated in a *UNESCO International Science, Technology and Environmental Education Newsletter* which advocates that a strong environmental education program should include a sound knowledge base, skills for citizenship and issue analysis and investigation and should help develop an internal locus of control (CONNECT, 1993). Other researchers suggest that a taxonomy of environmental actions can help make the knowledge more accessible for students and help systematize the knowledge. The taxonomy of environmental action that they suggest is reduce, recycle, replace and raise (Daniel, Stanisstreet, & Boyes, 2004).

**Student Misconceptions of Environmental Issues.** The main effects of human impact on environment result from industrial pollution and fossil fuel use which leads to a build up of greenhouse gases and from deforestation which leads to a decrease in the sequestration of carbon. Climate change is a complex issue and difficult to understand, thus resulting in frequent misconception in the understanding of students (Gowda, Rajeev, Fox & Magelky, 1997). These researchers found that the most common misconceptions of the students have included that students tend to overestimate the change in temperature as a result of climate change which is currently predicted to be about 1.5 degrees in the next 50 years. A second misconception that the students have is that they tend to overvalue the effect of chlorofluorocarbons (CFCs) on the ozone hole and climate change when they are actually less of a threat than fossil fuel use, industrial air pollution, and deforestation. A third misconception is that students most frequently cited warmer temperatures as a major climate change when the greater concern should be rising sea levels and increased storm frequency. Other myths that students divulged to these authors include that all environmental harms cause climate change, that improper
disposal of garbage could result in global warming and that students were not clear over the difference in weather and climate. In working with Chinese students, Duan and Fortner (2005) also identified climate change, deforestation, desertification, biodiversity loss, and ozone as other important topics that needed to be addressed.

**Student Understanding of Environmental Change.** Hausbeck, Milbrath and Enright (1992) evaluated the environmental knowledge, awareness and concern of students in New York State. These researchers conducted a survey of 3,200 11\textsuperscript{th} grade students in social science classes from 30 high schools. Approximately half of the students were from western New York while the rest were from other regions of the state. Demographics indicated that gender was closely balanced while almost 40\% were from urban areas, 30\% from suburban areas. More than three fourths of the students were either 16 or 17. The researchers found that very few schools offered environmental education. Knowledge scores ranged from 7\% to 95\%. The highest mean for any particular school was 63.8\% and the lowest was 34.9\%. When compared to a New York Board of Regents score of 65\% as a passing grade, no school had a passing grade. Private school students had more environmental education knowledge than public school students and city public schools had a dismal average of 42\%. Awareness and concern scores were considerably higher for all schools. The range of possible scores on these two parameters was from 7 to 35. The mean score for awareness was 27.1 and for concern was 26.5. School type did not appreciably affect awareness or concern scores but city schools scores were lowest on both awareness and concern. These researchers feel that the low scores on the knowledge segment of the instrument was a justifiable reason for including environmental education as a separate course in the curriculum. These
researchers advocated an environmental education curriculum that is multi-disciplinary, involves basic concepts, encourages integration of materials and holistic thinking, is problem oriented, addresses environmental problems that students are likely to encounter, involves value clarification, addresses local and global environmental issues and has a “hands on” nature.

While these findings are from a distant state with different students, the need for students to participate in environmental education is obvious. All of these articles indicated a need to address global issues, the need to prepare students to make informed decisions and to actively participate in scientific activities. The consensus of the research indicates the need for a holistic, problem-solving type of curriculum that can account for local and individual needs and provides a variety of activities with multiple means of assessment.

**Current Research in Environmental Education.** Gowda, Fox and Magelky (1997) evaluated student understanding of climate change. Areas of concern include the human impact on global climate through industrial pollution and fossil fuel use that lead to an excess of carbon dioxide and other greenhouse gases and the deforestation which removes carbon sinks that can naturally capture the carbon dioxide. In an effort to determine what misconceptions students have on these issues, these researchers conducted a survey on approximately one hundred students from Hawaii and Oklahoma. The instrument was an open-ended survey that allowed for multiple responses and was conducive to a large number of observations. Results of the survey indicated five areas of misconceptions that need to be addressed in environmental education. These include inflated estimates of global temperature change, confusion between chlorofluorocarbons
and the ozone hole and its affect on the climate, equating warmer weather as evidence of climate change, assuming that all environmental harms result in climate change and confusion between weather and climate.

Palmer and Suggate (2004) investigated the development of children’s understanding of environmental issues between the ages of four and ten years old. Three interviews were conducted at two-year intervals with 101 students from the northeastern portion of England. Interviews were focused on deforestation and global warming. The intent of the interviews was to evaluate the students’ development in knowledge and understanding of these issues, to identify common gaps of understanding and misconceptions. A series of photographs with key questions prompted the discussion which was led by a trained researcher. This research revealed the following key findings:

1) as early as four years old children are aware of distant environments, 2) the number of children that were able to provide accurate factual knowledge increased by about ten percent per year, 3) factual knowledge seems more robust than misconceptions yet misconceptions can withstand time, 4) four year olds can only conceive short term effects whereas children older than six can realize long-term effects 5) there is a high correlation between students who are cognizant of long-term effects of deforestation and global warming, 6) by the time students are ten they are aware that their actions may affect distant environments and 7) the ability to understand complex relationships between animals and their habitat increases with age. Although these conclusions seem logical, an apparent implication for dendrochronology is that younger students may not be ready to relate environmental change to tree ring measurements.
According to Gayford (2002), two of the major environmental problems of our time are biodiversity reduction and global climate change. Although global climate change is considered to be a controversial topic, most research indicates that global warming does exist and that human activity may cause it to escalate. Through a focus group approach, Gayford worked with four groups of four or five teachers that met three times each. The researcher served as a facilitator and observer. The groups consisted of volunteers who included global climate change in their science classes. An effort was made to determine how the topic was addressed in their classrooms. The basic question of the focus group was “How can global climate change be addressed in the science curriculum?” These teachers thought that the education that students received should be worthwhile and relevant to modern life, rational and linked to prediction, should develop the skills of inquiry and extend the students understanding, and should develop critical thinking so that students could evaluate information. Topics these teachers deemed necessary to adequately prepare students in the area of global climate change were the Earth’s atmosphere, energy transfer, wave properties, water cycle, plant growth and development, photosynthesis, pollution, plate tectonics, gas laws, materials, kinetic theory, and the planetary system. They described the characteristics of a good science course as one that would help the students develop an understanding of the nature of science, an appreciation for the historical perspective of science, and an appreciation for the process of science. Additionally, students should have an appreciation for the contribution of science to solving global problems, be able to make rational decisions based on information gleaned, appreciate the interconnection of global issues and local impact and realize that there is no one satisfactory answer to global problems.
Contemporary Research in Environmental Understanding. In examining the state of environmental education, researchers have evaluated student understandings and misconceptions of the environmental conditions. In working with pre-service high school teachers, Khalid (2003) identified the greenhouse effect, ozone depletion and acid rain as the most commonly misunderstood issues. This researcher found that these pre-service teachers understood that carbon dioxide was the most abundant greenhouse gas but incorrectly thought that the greenhouse effect was solely the responsibility of human activity.

One particular aspect of environmental education that is of particular importance is the ozone layer and the ozone hole. Leighton (2003) evaluated the current knowledge of students and adults on the ozone layer, their grasp of terminology associated with the ozone issue and their ability to arrange this knowledge into a model. Students in kindergarten, third grade, fifth grade and university students in an introductory psychology class participated in the study. In this qualitative study, the 120 participants were interviewed from one of two parallel interview forms that contained 11 questions with some subquestions. The adults were able to structure models of the ozone layer and implications of its depletion, yet only a few children were able to do so. The researchers also found that the ability to structure a mental model of the ozone did not imply full understanding of scientific nature of ozone layer and its depletion. Two conclusions from this study for environmental change education were that in teaching elementary students abstract ideas about the environment, pre-assessment of student knowledge would be advisable and that instruction should provide a means to help students scaffold knowledge needed to construct mental models of abstract concepts. Although the
research was directed toward elementary students, attention to prior knowledge and skeletal help for scaffolding knowledge would also be appropriate for middle school and high school students.

In an attempt to evaluate the environmental understanding of primary teachers, pre-service primary teachers and pre-service secondary science teachers in the United Kingdom, Summers, Kruger, Childs and Mant (2001) conducted a survey to determine their understanding of the carbon cycle and the global issues of biodiversity, the ozone and global warming. The survey was preceded by interviews with 12 primary teachers to obtain depth of information with a high validity and to reveal any misconceptions that needed to be included in the questionnaires. Knowledge of practicing teachers was greatest in the areas of biodiversity with a correct percentage of 64 and global warming with a correct percentage of 48. Corresponding scores for pre-service primary teachers were scores of 60% and 50%, respectively. These were comparable to those of practicing teachers. The pre-service secondary teachers, who only took the ozone and global warming questionnaires, scored higher than primary teachers and seemed to be most knowledgeable about global warming.

In a questionnaire administered to college students in Stanford University or Costa Rica, Holl, et al (1999) found that knowledge about the environment and human population growth is quite low. Recycling is listed as the most often used change in preserving the environment although also listed were minimizing personal automobile use, selecting environmentally friendly products or conserving water. These authors stressed that it is important to teach the link between environmental issues, that teachers must make sure that students understand the relationship between individual actions and
the environmental quality and that information on environmental problems and solutions needs to be tailored to fit the needs of the community and the individual student.

Examination of the literature reveals that the major misunderstandings include greenhouse effect, ozone depletion and acid rain as the most commonly misunderstood issues. There is also evidence that students may fail to see what actions can prevent environmental change and can misinterpret the impact of humans on the environment.

Dendrochronology

Foundation of Dendrochronology. Even though Theophrastus, a student of Aristotle, knew that fresh growth formed on the outer circumference of a tree and Leonardo da Vinci recognized the annual character of tree-rings and deduced a relationship between ring width and moisture availability, dendrochronology, the use of tree rings as record keepers, is a relatively young science that was established in 1921 by the astronomer A.G. Douglass (See Appendix N.) (Baillie, 1982). Although it was previously known that the size of tree rings was directly related to growing conditions, Douglass was the first to use the rings as chronological record of past climatic conditions when he attempted to relate solar activity to tree rings growth patterns (Webb, 1983).

Environmental factors that can affect tree growth are abundance or lack of nutrients, water, and radiant energy (Grissino-Mayer, 2005). According to Grissino-Mayer, to study dendrochronology one must be familiar with the following principles: (1) The uniformitarian principle assumes that the physical and biological conditions that caused the changes in tree rings in the past are the same as those that affect tree growth now. (2) The principle of limiting factor states that the rate of growth is limited by the physical or biological factor that most stresses the organism. (3) The principle of
aggregate tree growth states that the growth of a tree is an aggregate of factors that affect
tree growth and may include the normal aging process, climate, disturbances within the
forest, disturbances outside the forest, and random error. (4) The principle of ecological
amplitude states that trees growing on the margin of their habitat range are the most
useful trees for dating events using tree rings. (5) The principle of site selections states
that the best site to select for examining a particular factor would be the site that makes
the trees most sensitive to the factor being studied. (6) The principle of cross dating states
that tree ring width and other tree ring characteristics of a tree for a year can be matched
to the similar rings in other trees for that year. (7) The last principle of replication states
that multiple analyses of different trees improve the reliability of the data obtained by
reducing the effects of extraneous variations seen in tree ring growth patterns.

Because tree ring analyses are consistent with the historical data for such natural
disasters as volcanic eruptions and tsunamis, they can provide an accurate timeline that
can be extended to prehistoric times (Baillie, 1982). Consequently, dendrochronology is a
tool that can be used to assess changes in our environment as well as document past
historical events. The visual nature of the tree ring samples used in dendrochronology
makes this science an ideal tool for students to investigate environmental change using
human constructivist methods. With tree rings students will be able to see visual effects
of the environment, quantify and use replication, construct graphs, improve observation
skills, and make connections between two different variables such as size of rings to
growth conditions, sunspots or El Nino (Hughes & Swetnam, 2004).

Branches of Dendrochronology. Specific examples of how dendrochronology can
be used in research include the work in paleoarchaeology. Baillie works with
dendrochronology with respect to archaeology at Queen’s University in Belfast, Ireland and suggests that the three broad chronological divisions of archaeology include the last millennium, the period that spans the first millennium AD and the first millennium BC, and the prehistoric period. He suggests that dendrochronology can be integrated with history and archaeology and that radiocarbon dating can further substantiate dendrochronological claims (Baillie, 2002). Similarly, Kuniholm, who works at the Malcolm and Carolyn Wiener Laboratory for Aegean and Near Eastern Dendrochronology at Cornell University, declares that “dendrochronology is still the only archaeometric technique which is capable of annual or even sub-annual resolution” (64) (Kunniholm, 2002). He lauds the fact that dendrochronological methods are still quite simple and that accurate ring identification that can be done by eye. There is a link between culturally defined stratigraphy and dendrochronological dating for late prehistoric times and the chronology of a European oak goes back to 8000 years.

Dendrochronology has also served as a tool for relating atmospheric conditions to forests production. McLaughlin, Shortle and Smith (2002) describe dendroecology as the application of dendrochronology to analysis of the ecological issues involving tree biology, forest ecology and soil biogeochemistry. Statistical analyses have been used to determine the responses of forests to climate changes due to physical and chemical factors through the analysis of both tree rings growth and wood chemistry they also examined the physiological mechanisms of how air pollution alters tree biology. Specific air pollutants shown to affect tree physiology and growth are ozone and carbon dioxide, though these authors stress that the relationship of tree growth to environmental conditions is quite complex (McLaughlin, Shortle, & Smith, 2002). These claims are
reiterated by Ferretti, et al. (2002) who suggest that the impact of air pollution on forests should be examined on local, regional and global levels. They specifically suggest that positive environmental factors that affect tree growth include increased atmospheric carbon dioxide levels, increased nitrogen fertilization and global warming. Ozone and endogenous factors such as long-term growth curves may negatively affect tree growth and have been implicated in the defoliation of spruce trees in Europe during the 1990s. These authors suggest that examination of other tree physiological features such as tracheid length and cross sectional area and wall thickness in late wood can be used to substantiate ecological claims based on dendrochronological results. Though dendrochronology has been a tool for studying modern environmental effects, Martinelli (2004) suggests that it also has a strong influence in paleoenvironmental studies through providing annual, decadal and century time scales. Tree ring reconstructions can span a thousand years and have been linked to both precipitation and temperature. Such reconstructions have been made with a variety of tree species and in Europe, Asia, and South America.

Dendroclimatology uses dendrochronology to reconstruct the natural variability in the Earth’s climate (Hughes, 2002). Hughes suggests that establishment of climate data from the past several centuries can be used to corroborate with the climatic data of the last few millennia. Specific areas in which dendrochronology have been helpful are in studying the cyclic features of environmental variability such as the El Nino Southern Oscillation, reconstructing the surface temperature for the last millennium that suggests the 20th century has been uniquely warm, and examining the role of solar and volcanic forcings which contribute to climate variability. Hughes (2002) suggests that the work of
Fritts in establishing the International Workshop on Dendroclimatology in 1974 has been very important in developing fully dated and documented the tree-ring chronologies that have advanced the field of dendroclimatology. Other important researchers in the field of dendroclimatology include Schweingruber and Briffa. Through cross dating or matching tree ring patterns across trees and regions up to 2000 km long, tree ring chronologies have been used to corroborate data from natural archives such as ice core samples and fossil pollen which cannot be as precisely dated.

Dendrogeomorphology is the specific field in which plant ecology and dendrochronology are used as research tools in the field of geomorphology. Geomorphic events that produce stress can result in suppression of tree growth as evidenced in narrow tree ring growth, tilting, shear of roots or trunk, corrosion (abrasion leading to an open wound where bark has been removed), burial of parts of the trunk, and exposure of roots.

**Tree Anatomy.** Evaluation of tree ring data is possible because of the anatomy of a tree (see Appendix O). The wood of a tree contains secondary xylem which has three elements: tracheary vessels that move water, fibers that provide support and parenchyma cells which translocate of food exhibit (Baillie, 1982). In a cross section of a tree, the xylem exhibits alternative bands of light and dark growth. Generally, light areas indicate periods of fast tree growth during the best growing season when sunlight and rainfall are optimal and dark areas indicate areas of slow or no growth during times of drought, flood or low sunlight. In addition to growth conditions, tree rings also provide documentation of insect damage, retarded growth due to tree crowding, evidence of compensatory growth and change due to environmental factors.
The annual rings that are visible in a cross section of a tree trunk have a pattern that allows inferences about the tree’s growth. Because the magnitude and speed of growth of trees occurs only during warm seasons in temperate climates, tree growth rings can be used to determine the chronologies of geologic events. Environmental factors that can affect tree growth and cambial activity include availability of nutrients, climate and weather, soil, rainfall, light, wind, snow, and unstable soil, defense mechanisms such as resin formation and heartwood formation (Schweingruber, 1993). Generally observations used to determine age and overall condition are macroscopic characteristics of tree rings, but closer examinations should include ring width, latwood width, density variations, callus tissue, and healing tissue. Event years and abrupt changes in tree growth are characteristic and ecologically significant in developing chronologies since they allow comparison from tree to tree and may indicate form of ecological change (Schweingruber, 1993).

In conifers, the xylem in conifers is composed of tracheids that are long thin cells with both ends tapered and closed. Within the annual ring of a conifer, the tracheids formed early in the season are called earlywood and are thin walled, light in color and have large cavities. The latwood tracheids are thick walled, strong, dark and have small cavities. The last tracheids of the latwood and the beginning of the earlywood of the next year provide a strong contrast that allows the identification of the annual rings growth (Stokes & Smiley, 1968). However, tree rings can only be used for dating if conditions exist that allow for variation of tree growth between years and allow for visible differences in early wood and late wood. Stokes and Smiley state that conditions that must exist for tree ring data to be used for dating a tree include (1) there must be only
one ring per growing season so that each ring represents a year's growth, (2) there must be
only one dominant environmental factor that affects growth so that the majority of the
tree growth is reflected by that factor, (3) the limiting growth factor must vary from year
to year to allow for changes in growth ring sizes and (4) the environmental factor must be
effective over a large enough area to allow comparisons between trees.

Abrupt changes in growth reveal changes occurring over more than three years
whereas conspicuous or odd tree rings indicate event changes of 1 – 3 year duration.
Width fluctuations that are constant reveal the dynamics of aging and conditions. Density
variations, unclear tree ring boundaries and wedging rings are a result of climatic factors.
In using conifers for dendrochronology, formation of compression wood, as indicated by
rounded thick walled tracheids, is evidence of a change in the site (Schweingruber, 1993).

Trees Used in Dendrochronology. In addition to environmental conditions,
physiological conditions also are involved in the characteristics of tree rings (see
Appendix P). Low moisture results in narrow rings, whereas moist conditions result in
wide rings (Schweingruber, 1993). Monocotyledonous trees do not form rings and the
annual rings of deciduous trees are generally harder to differentiate than those of conifers
(Butler, 1987; Schweingruber, 1993). Because there is little variation in tree ring size in
regions of high precipitation, these trees are difficult to use in cross dating. Similarly,
where there is a continuous growing season such as in the tropics, trees lack the
deviations in tree ring characteristics that allow for dating and other environmental
evaluations. Hence, the best trees for tree ring dating are those found in temperate regions
where some factor such as precipitation causes visible variations in the annual tree
growth. However, as suggested by Grissino-Mayer (2005) the most suitable tree for
relating tree growth to some factor would be the type of tree most sensitive to the factor being tested.

Sample Preparation. Evaluation of tree ring data is dependent upon properly obtained and prepared samples. The techniques for sample preparation are still based on the seminal work of Stokes and Smiley (1968) and is depicted in the concept map of Appendix Q. Conditions necessary for tree ring evaluation and dating to be effective and valid are that only one ring is deposited by the tree per growing season, that there is only one primary growth limiting factor which varies from year to year and that this factor is uniformly effective over a large area.

Stokes and Smiley state that the two basic techniques for obtaining samples is to cut a cross section from the tree at breast height which requires that the tree be felled or by taking a sample 5 to 8 mm in diameter from the living tree through use of a tree borer. Tree core samples are then air dried then glued on a slotted mount. Regardless of sampling technique, preparation of the sample involves progressive sanding with abrasive paper from coarse grit (No. 60) to fine grit (No. 400). The resulting samples will reveal dark and light bands of the tracheids which can be both counted and quantitatively measured through x40 magnification. These authors recommend that skeleton plots be constructed for each sample to provide a permanent record of the measurements and to forestall repetitious evaluations of the same sample.

Dendrochronology in Environmental Change Research. Currently dendrochronology includes the branches of dendroarchaeology, dendroclimatolgy, dendroecology, dendroentochronology, dendrogeomorphology, dendroglaciology, dendrohydrology, and dendropyrochronology and research is being conducted in all of
these areas (Grissino-Mayer, 2005). More specifically, Hughes and Swetnam (2004) describe dendrochronology as a tool for climatic research.

At the International Workshop on Dendroclimatology, in Tucson, Arizona in 2003, seventy five scientists from ten countries met to discuss what tree ring information has contributed to the knowledge on climate variability and the strength and weaknesses of dendroclimatology (Hughes & Swetnam, 2004). Tree rings have provided archival data on temperature, precipitation, stream flow and the Palmer Drought Index. Scientists have used dendrochronology to reconstruct circulation indices such as the Southern Oscillation Index. Tree rings have also provided a means of evaluating the effects of volcanic eruptions on climate and have been a chief source of data for reconstructing temperature histories for multiple centuries. Dendrochronological data has also been used to substantiate the opinion that the last 20 years of the twentieth century has been exceptionally warm. Hughes and Swetnam recognized one weakness of dendrochronology as the limitations in detecting slower climatic changes on a multi-century scale.

One specific example of dendrochronological research related to environmental change was conducted by Carrer and Urbinati (2001) in the Italian Alps. In this study the researchers investigated structural and dendrochronological features as a function of spatial pattern. In the Eastern Italian Alps, these researchers studied a mixed conifer forest of European larch, Arolla pine and Norway spruce. Dendrochronological data obtained were mean sensitivity, first order serial autocorrelation of raw values and tree-ring growth indices for the period of 1926-1994 and fine scale spatial pattern of tree ring growth. These data were used to assess the tree response to variance in environmental
factors and the percent variance that could be accounted for by climate and maximum
temperature in June.

In the 583 trees that were evaluated, these researchers found that autocorrelation
and means sensitivity were not affected when trees grew at a distance greater than 5
meters apart. This research implies that the use of dendrochronological data for climatic
purposes is not affected by distance of tree separation although extreme weather
conditions cause a clear effect. Although tree species and geographic location may affect
results, implications for application in a high school setting is that consideration for tree
spacing may be a factor in determining tree ring growth in locally grown trees.

In the United States, Elliott and Baker (2004) correlated one hundred years of
climate record on the invasion of quaking aspen into conifer stands in the San Juan
Mountains of Colorado. Tree core analyses were used to reconstruct ecosystem changes
and were compared to temperature and precipitation data for Telluride, Silverton and
Lake City. These samples were used to date trees to determine when aspen invasion had
occurred. These authors determined that aspen invasion had occurred since 1900. Based
on tree ring data, they postulated that that aspen invasion by seed production was related
to wet seasons and that during warmer conditions invasion occurred through the asexual
reproduction of root suckering. High school students in the Deep South may be interested
in similar invasive effects of Chinese tallow, locusts or pines in abandoned crop fields.

Current Pedagogical Practices in Dendrochronology. While tree rings offer a
visual chronology of a tree’s life and can provide a history of the surrounding habitat, it
has rarely been used as an instructional tool, especially in high school science classes.
Palmer (1986) used dendrochronology to help ninth grade students develop skills in
determining the relationship of tree ring size to precipitation data and then used 200 year weather data to estimate the age of timbers and date when they were felled. Though dendrochronology did provide an excellent way to improve measurement skills, graphing skills and ability to recognize corelationships, Palmer showed no evidence that the activity promoted inquiry-like thinking nor was there any empirical data to show the efficacy of his lessons in promoting scientific thinking.

Another classroom example of dendrochronology is the work of Butler (1987) in an undergraduate introductory geology class. Butler used tree ring analyses to reconstruct the history of geomorphic processes and to show the principle of recurrence interval. Again, pedagogical techniques are well described and pitfalls are noted but no scientific data is presented to substantiate his claims.

Metzger (1994) suggested that one of the fundamental concepts which all science students should be aware of is that our planet is undergoing change at all times. Although many of these changes are cyclic, they are so gradual that we cannot observe them directly. Additionally, human activities may have a detrimental affect on these geocycles. Thus, Metzger advocates the use of activities that allow student to observe the Earth’s cycles and how man can affect them. One such activity that she suggests is the “Laws of Straw: Dendrochronology” unit as developed by the USGA. Here again, dendrochronology is touted as an excellent activity but there is no data to support her claims.

Sheppard (2002) also used dendrochronology as an instructional tool in a lower level non-science major course on Environmental History of the Southwest. Sheppard developed two web-based tools that were used to teach dendrochronology in connections
with forest fire management and crossdating. He concluded that the tools did help students understand crossdating and the significance of fire management more thoroughly. This author did not address the needs of high school science and did not discuss the applications of dendrochronology for assessing environmental change. He did, however, provide access to the cross-dating simulation through the internet.

Rubino and McCarthy (2002) used tree ring studies to teach botany, ecology and statistical principles to undergraduate students in botany. These authors indicated that use of dendrochronology provided opportunities for scientific methodology and hypothesis formulation and testing and promoted meaningful discussions that students could connect to their own lives and understanding. Rubino and McCarthy observed an improvement and an increase in the use of botany skills, a better understanding of tree physiology, and a better grasp of how extraneous factors affected plant growth. Yet again, these authors failed to supply scientific data to support their claims. Thus, the advantages of using dendrochronology as a teaching strategy have been documented, but empirical and quantifiable evidence is not available in the literature. Consequently, a research project that can substantiate the effectiveness of dendrochronology in the classroom would be quite valuable.

**Mixed Methods Research**

Mixed methods research is a class of research in which the research combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single study. Mixed methods are often employed in applied settings where practical decisions stress the utility of multiple data sources for decision making purposes (Johnson & Christensen, 2004). These authors suggest that in mixed research,
both deductive (quantitative) and inductive (qualitative) reasoning is used. The mixed method researcher sees behavior as somewhat predictable, has a multilens focus and multiple objectives. Behavior is studied in more than one context or condition and the nature of reality is common sense realism with a pragmatic view of the world. Data is collected in multiple ways and may be in the form of variables, words or images. To interpret the data, they look for patterns, themes and holistic features and statistical relationships. The final report is both eclectic and pragmatic.

Johnson and Onwuegbuzie (2004) suggest that methods can be mixed in two ways. When methods are mixed across stages, the research is called mixed model while mixed methods uses a qualitative paradigm for one phase of the research and quantitative for another stage. These usually occur during the data collection stage of the research. In the mixed model research both qualitative and quantitative methods are used within a stage or across two of the stages in the research process. For example, if the research objective is qualitative, such as an exploration question and description, the data may be collected in a numerical manner which is quantitative.

The advantages of mixed methods research is that it provides multiple perspectives, theories and research methods when the two paradigms are used to complement each other. One fundamental principle of mixed methods is that it is wise to collect multiple sets of data using different research methods in such a way that the resulting mixture or combination has complementary strengths and no overlapping weakness thus lessening the chance of making an error. The complementary strengths often seen in mixed methods works are that words and pictures lend meaning to numbers while numbers give precision to words and pictures. By using a grounded theory one can
generate and test a grounded theory and can answer a broader and more complete range of questions. Conclusions reached with mixed methods are corroborated through triangulation and convergence and can give insights and understandings that might be missed when using only one paradigm.

Weaknesses of mixed methods are that the researcher must be competent in many areas of research and the work may be difficult for a single researcher. Expense and time are also a factor since more of each is needed. Occasionally the research may be conflicting between the paradigms.

Teddlie and Tashakkori (2003) describe six paradigms that dictate the type of mixed methods used. These authors contend that the degree to which the research can be mixed depends on the viewpoint. The two paradigms may be of equal strength or one may dominate. The two portions of the research can be completed simultaneously or sequentially. They include a-paradigm in which scholars believe that methods and paradigms are independent of one another and so mixed methods are permissible. The incompatibility stance is that paradigms are incompatible so quantitative and quantitative cannot be mixed. This is now considered to be an outdated stance because of the prevalence of mixed method research in the social sciences. In the complementary stance, scholars believe that mixed methods are possible but that they must be kept separate so that the strength of each paradigmatic position (postpositivism, constructivism) can be realized.

Supporters of the complementary strengths thesis of mixed methods research feel that the assumptions of each paradigm must be kept but that the two parts should be kept as separate as possible in order to realize the strength of each paradigm. They see an
advantage of this stance as the use of triangulation (looking at the situation in more than one way in order to get a truer picture of the situation). The single paradigm stance is that a single paradigm should be used as the foundation of research. There are two views of this stance; the pragmatists feel that the research question dictates the paradigm and the transformative-emancipatory researchers feel that the social issue dictates the paradigm. The dialectic view does not advocate one paradigm over another but rather sees mixed methods research as intentionally engaging a multiple set of paradigms and their assumptions. They see all paradigms are valuable but give only a partial world view. By thinking dialectically or by examining the tensions that emerge from the juxtaposition of these multiple diverse perspectives one can see the nuances of the research situation.

**Summary and Conclusions**

Currently available research on environmental change shows that authorities are most concerned with global climate change, ozone depletion and loss of biodiversity. Much of the evidence describe environmental issues as controversial with no clear-cut solutions, thus indicating that simply providing students with facts will not be productive. This is corroborated by the literature on environmental curriculum published in the early nineties which shows that students were inadequately prepared in this area. In an editorial in *Education Week*, deBettencourt (1999), the executive director of the Environmental Literacy Council, states that most Americans are ignorant of global environmental problems. She feels that environmental education is filled with trivial activities, poor materials, and poorly trained teachers with much of the curriculum devoted to convincing the students that the environment is in danger. The Environmental Literacy Council
advocates the improvement and accuracy of texts and the development of appropriate environmental science standards.

Research of that decade makes it apparent that students from kindergarten up and even primary school teachers need to be better informed of environmental change. The Environmental Literacy Council would like to see a curriculum that encourages student projects that are multi-disciplinary, are inquiry-based and will spark an interest and concern in the environment. Though more searching needs to be done to more accurately identify the state of environmental education at the present, it appears that students need to be taught environmental issues through a holistic, problem solving approach which allows for personal connections and active, meaningful learning.

Joseph Novak’s theory of education seems to be a sound philosophical base for establishing an educational program on environmental change that is holistic and problem solving in nature. The metacognitive ideas and scaffolding approach of the human constructivist philosophy which underlie his theory meld well with the controversial topics of environmental change. Use of the 5E lesson design, accompanied with the teaching strategies of self-reports, concept maps and roundhouse diagrams would be strategies that actively involve the students and would allow them to construct meaning in a way that is personally appropriate.

Dendrochronology is a research technique frequently employed by scientists to evaluate forests, to document past climatic change and environmental effect and to document the age of archaeological findings. It is frequently tied to research in the area of global climate change and can provide record of past environmental effects for long past centuries. The visible nature of the tree rings makes it an interesting phenomenon for
students and its use in the classroom has been documented in the literature. However, empirically based literature on the use of dendrochronology in the science classroom is lacking. Thus research that can document the effectiveness of dendrochronology as a tool to develop understanding of environmental change through current pedagogical practices would be quite appropriate.

Research in science education indicates that judicious use of human constructivist ideas in well designed units with carefully constructed assessment instruments can help students construct meaningful knowledge while helping them to develop good inquiry and metacognitive skills that can make them productive citizens capable of sound decision making. A unit built on dendrochronology that addresses local issues, makes connections to other disciplines and shows the long-term effects of climate on tree growth may help accomplish this task.
Methods

Problem Statement

Based on the publications of the American Association for the Advancement of Science (AAAS) (1990) and the National Research Council (NRC) (1995), constructivism has become the favored mode of instruction in science classrooms. The advantages of constructivism are touted as being able to produce students who are independent problems solvers and more ready for the real world. Additionally, human constructivist classrooms allow for individual differences and recognize the student as the chief architect of his own learning (Mintzes, Wandersee, & Novak, 1998). The AAAS Project 2061 has a long-range mission of reforming K – 12 science and mathematics education in the United States and has established national standards and benchmarks to help teachers attain these goals. Numerous units developed around these guidelines are available. Yet often, the units of study that address the specific needs of one region of the country may not necessarily address the needs in other areas of the country. Consequently, the focus of this study is an attempt to develop a dendrochronology unit that could be used to help high school environmental science students gain a better understanding of environmental change through a study in dendrochronology.

Dendrochronology, or tree ring dating, is the study of the annual growth rings in trees and can be used to make inferences about past climatic conditions or natural disasters in the tree’s environment. The visual nature of the tree ring samples used in dendrochronology make this science an ideal tool for students to investigate environmental change using human constructivist methods. With tree rings students can
see visual effects of the environment, quantify and use replication, construct graphs, make connections between two different variables (size of rings and growth conditions or sunspots or El Nino), and improve observation skills. Since dendrochronology is intimately involved with environmental issues, the resulting unit can fit the needs of any science teacher in grades K – 12 where forestry is a dominant industry.

Research Design

This research study was an exploratory investigation of how dendrochronology can be used to help students learn more about environmental change through participation in a multi-activity unit that actively involves the students in investigating environmental change. This ten day unit was designed using a number of instructional strategies that are thought to improve meaningful learning. The primary research purpose was to determine the value added to students’ understanding of environmental change when an innovative experiential unit on dendrochronology was included in a high school environmental science course. Because the nature of the study was explorative and because a mixed methods approach can provide an opportunity to substantiate data, the data collection had both a quantitative portion and qualitative portion. A research Vee diagram and the concept maps that guided this project are shown in the Appendices.

Research Site

The site chosen was one of convenience since the researcher teaches at the school. The high school chosen was a rural high school where forestry and forestry products are a dominant industry. This school is a Title One school with a high poverty level. Student population at the school is approximately 60% white and 40% minority and enrolls approximately 700 students in grades 9-12. Instruction at the school is based on a four by
four block schedule in which classes meet ninety days for 90 minutes per class session.
Because students enroll in four classes in both the fall and spring semester, a student can receive eight Carnegie units per year. The school typically offers two sections of environmental science each semester. This research was conducted in the fall semester of 2006 semester with two Environmental Science classes.

**Research Participants**

The environmental science teacher at the research site typically teaches environmental science in both the fall and the spring terms. Although sections generally average 16 to 24 students, the actual number of students enrolled for the Fall 2006 semester was comprised of 25 students. Environmental science classes were chosen since this is frequently the last science class that many students take, the curriculum provides more flexibility for innovative inquiry studies and the national standards of environmental science most closely fit the objectives of the proposed unit.

A flowchart of the research with artifacts gathered is in Appendix R and a timeline of the research is presented in Appendix S. The researcher has completed the National Institute of Health on-line human subjects training module for “Human Participant Protections Education for Research Teams” and has obtained an LSU International (IRB) Exemption from Institutional Oversight. (See Appendix T). All personal information obtained was kept confidential and there were no foreseeable ethical threats to any of the participants.

**Data Collection**

Although the success of the dendrochronology unit can be partially described by the quantitative data collected from the pre- and posttests, analysis of qualitative data can
provide insights into particular areas that the students, teachers and interviewers found most effective and can lend validity to the quantitative portion of the study.

The quantitative portion consisted of a one group pretest-post test design as described by Johnson and Christensen (2004). Mode of instruction served as the independent variable and student achievement as measured by the difference in the pre- and posttests scores served as the dependent variable. The pretest and a demographic questionnaire were administered immediately before the beginning of the intervention. The posttest was administered one day after completion of the intervention.

Qualitative data was ongoing and included structured interviews adapted from the interview guide suggested by McMillan, Wright and Beazely (2004) for university environmental science students, as well as field notes, journals, and student created artifacts such as small multiple graphics, student sketches, and student research projects. The introductory and summary lessons were videotaped and analyzed by two observers (the researcher and the teacher participant). A purposeful sample of three students from each class was selected for the structured interviews, which were tape-recorded. Student selection was based on willingness to participate and included a high performing, middle performing and low performing student from each class.

Unit Preparation

Using the National Science Standards and the Louisiana Grade Level Expectations, a human constructivist based unit (shown in Appendix U) was designed after surveying the current literature on dendrochronology, environmental science, and current science teaching methods (National Research Council, 1995; Louisiana State Board of Education, 2005). Specific standards to be addressed are listed in the unit plan.
and include those attending to the abilities to understand and participate in science as inquiry, biodiversity of organisms, energy of the earth system, origin and evolution of the Earth and geochemical cycles. Inquiry design was based on the materials established by Bybee and Novak and included student research projects and other products based on human constructivist ideas (Mintzes, Wandersee & Novak, 1998; Cothron, Giese & Rezba, 2000). Master teachers in environmental science and experts in the fields of education, dendrochronology and environmental science were engaged in evaluating the unit and pre and posttests in terms of pedagogy and content, and adjustments were made accordingly.

**Conceptual and Operational Definitions**

Dendrochronology unit – a researcher developed inquiry-based unit in which students use analysis of tree rings to make inferences about the environment.

Evaluation – the appraisal of all components of an educational system.

Formative Assessment – ongoing evaluations of the participants of the research throughout the intervention including student artifacts and works.

Four by Four Block – school scheduling system in which students are enrolled in four classes per each eighteen-week section. Students attend class 90 minutes per day for each Carnegie unit of credit. Two terms are taught each school year allowing students to earn up to eight units of credit per high school year.

Human constructivist instruction – intervention by which students learn science by doing science as scientists do through questioning, researching, experimenting and communicating their findings. Classroom activity stresses meaningful learning, is student focused and uses performance-based assessment.
Roundhouse diagrams – a metalearning tool developed by Wandersee that allows students to graphically organize the information into a seven sector hub that shows their relationship to a central topic (Ward and Wandersee, 2002).

Scope-on-a-Rope – handheld microscope that projects the image on a television screen

Small multiple graphics – student created artifacts based on the ideas of Edward Tufte in which students generate several graphics of similar styles to compare and contrast ideas.

Student performance – the dependent variable in this research which is operationally defined as the improvement in score of the students from the pre- and posttest scores and final exam scores.

Summative assessment – evaluation of a student at the conclusion of a unit to determine the effectiveness of the instruction.

Tree cookie – cross sectional cut of a tree that has been progressively sanded to enhance the visibility of annual tree rings for counting purposes.

Understanding of environmental change – the dependent variable which is the degree to which students understand how the environment is affected by different factors. Specific issues to be addressed include ozone depletion, climate change, deforestation, species change and factors which can alter any of these phenomena. This will be determined through a variety of quantitative and qualitative measures including difference in pre- and posttest scores, student artifacts, student journal and interviews, teacher journal and interviews, and researcher field notes.

Procedures

Intervention. The specific intervention used in this study was the implementation of a two week dendrochronology inquiry unit based on Bybee’s 5E model of instruction
with the stages of Engage, Explore, Explain, Elaborate and Evaluate (Bybee, 1997). Students were introduced to the lesson through a one-day engagement activity that had the students compare the tree ring growth patterns of two very different trees. During this stage students sketched multiple graphics to compare the anatomy of the trees. Using available climatic data students graphed temperature, precipitation and tree growth versus time to determine if there were any apparent similarities. Using a webquest the students investigated environmental and climate change and used these new ideas to develop inquiries to explore factors that affect tree growth through experimenting and literature search. The students then developed inquiries to explore factors that affect tree growth through experimenting and literature search. Instructional time was provided for students to investigate tree anatomy and to explore factors that affect tree growth. In the elaborate phase, the students used the remaining five days to develop and present environmental effect studies on tree ring growth. Students maintained journals throughout the intervention and designed and conducted research projects on trees. Artifacts generated during the intervention included, roundhouse diagrams, graphs, and small multiple graphics.

**Materials.** Materials needed to complete the study included previously prepared tree cookies, tree corer, tree core mounts, sandpaper, Scope-on-A-Rope (a videoprobe microscope), graph paper, metric rulers, data analysis software such as MS Excel, presentation software (MS PowerPoint), Inspiration software, Internet access, video recorder, tape recorder and drawing supplies.

**Instruments.** Instruments for use in this study were selected and modified by the researcher. Selection process involved a balance of meeting the objectives of this study,
addressing the National and State Science Standards that were to be covered in the unit and fitting the needs of the students and teachers participating in the research. Instruments selected include:

1. Structured interview guide adapted from that of McMillan, Wright and Beazely (2004).

2. Pre- and posttest which contains 22 multiple choice items on ozone, climate change, air pollution factors, water cycle, water table and biodiversity. Some of the items were taken from an environmental science final constructed by the participating teacher and had proven successful in previous classes. Items selected were those that addressed the National and State Standards addressed in this unit. Additional items were included to assess other objectives and standards not addressed in the original examination.

3. Student artifacts including multiple graphics, roundhouse diagrams, and student poster sessions. Inclusion of these artifacts was necessary to provide a means of assessing student achievement that is not easily evaluated with pen and paper tests.

**Internal and External Threats.** A major threat to the study was the weakness of a one group pretest-post test design experiment as reported by Johnson and Christensen (2004). However, only two classes of environmental science are taught at the available site per semester. It is unlikely that the same environmental science teacher could instruct the two different classes in two different manners without contamination of teaching methods between the two classes. Thus, any differences experienced in the pre- and posttest were substantiated with qualitative evidence. The threat of nonrandom sampling
was unavoidable due to administrative constraints, but the support of qualitative data should improve validity of the data. The threat of test wiseness has been lessened by including multiple forms of the test.

Because the designed unit was prepared for and was tested on high school juniors and seniors who have a natural interest in forestry, this research is deemed to be most applicable to students who fit this profile. However, it is expected that the unit and instruments could be adapted to fit the needs of other populations such as middle school or beginning college environmental science classes.

Trustworthiness of qualitative component was enhanced by triangulation of method through obtaining data from various sources (interviews, field notes and student artifacts), over time by observations at various key intervals and by having more than one observer coding and interpreting data. Participants were consulted to insure that communications with participants have been accurately interpreted.

Due to the specific age level, results of this study can best be extrapolated to high school environmental science students though adaptations of this study could be made to accommodate other instructional levels. Similarly, applicability of the research is limited by the enthusiasm of both the teachers and students. One could not expect the unit to be successful if the teacher cannot be enthused by environmental issues.

**Data Analysis**

1. Describe the environmental science teacher who participated in teaching the experimental dendrochronology unit to environmental science students in terms of personal, professional and school demographic characteristics.
This question was answered through personal interview using the interview guide in Appendix V.

2. Describe high school environmental science students who participated in the experimental dendrochronology unit in environmental science in terms of age, sex, race, socioeconomic status, grade point average and standardized test scores.

   This question was answered using the student interview format presented in the Appendix V.

3. Use human constructivism ideas to design a high school environmental science instructional unit on dendrochronology that addresses national standards and contains multiple metacognitive and meaningful learning strategies such as vee diagrams, concept maps, journaling and student designed inquiry.

   This question was answered by having the unit evaluated by experts in the field which included the members of this committee and the participating teacher.

4. Assess the affective and instructional value of a high school environmental science instructional unit on dendrochronology through analysis of interviews given to participating environmental science teachers and selected students.

   Qualitative analysis of student work was evaluated using emergent themes analysis.

5. Analyze pre- and posttests that addresses both environmental standards and science processing skills to assess the instructional value of a high school environmental science instructional unit on dendrochronology on the high school environmental science students participating in the course.
Quantitative data from the test (see Appendix W and X) included descriptive and inferential statistics. Pre- and posttest scores were analyzed using the Wilcoxon matched-pairs signed-rank tests (Hinkle, Wiersma & Jurs, 2003). The tests were designed so that the reliability of the multiple choice portion of the test could be evaluated using a split-half reliability coefficient using the Spearman-Brown prophecy formula (Ary, Jacobs & Razavieh, 1996). Each construct was tested with two questions which were divided between the odd and even numbered questions.

6. Describe and analyze the graphic representations constructed by the high school environmental science students participating in a high school environmental science class.

Graphic representations were evaluated on the basis of accuracy and completeness relative to expert diagrams.

Qualitative data analysis was a combination of case study analysis and phenomenology. The researcher, the teacher and students maintained detailed, descriptive logs of the activities completed during the unit. These were evaluated on an emergent coding system developed around the concepts of environmental understanding and science processing skills. Although interviews of the teacher and students were recorded and were structured, relevant deviations occurred when deemed productive. To ensure trustworthiness, at least two persons analyzed all interviews. Three students from each intervention class were purposively selected for these interviews to provide maximum case sampling.
Summary

Dendrochronology has long been used as a tool of scientists to explore, determine or confirm environmental and climatic conditions in a particular region. However, it has not been established as an instructional tool that can help students understand environmental and climatic changes. The goal of this research was to explore the use of dendrochronology in the science classroom to determine if it can enhance student understanding of environmental change through providing an opportunity for the students to engage in active learning that provides a chance for them to construct their own knowledge in a way that is meaningful to them. Through a mixed methods approach with both quantitative and qualitative components, the value of the unit was determined through student and teacher interviews, pre- and post tests, and student artifacts such as multiple graphics, student created diagrams, roundhouse diagrams and student created inquiries.
Results

Overview

The data for this research was acquired through the use of mixed methods in which quantitative data was obtained through formative and summative student assessments of the various activities and qualitative data was accumulated through student reflections and journaling, selected student interviews, teacher interviews and journals and researcher observations journaling. Using both techniques concurrently afforded a more complete data set that provided a better insight into the effectiveness of the dendrochronology unit that had been developed.

Participant Description

Students. A survey shown in Appendix V was given to the participating classes in order to determine their demographics. The two classes of environmental science that participated in the class consisted of 19 seniors and 6 juniors in two classes of 11 and 14 respectively. The range in age was from 16 to 19 with the mode being 17. Sixteen of the students had aspirations of attending college while three planned to go to technical school, one into the armed forces and five into the workforce. When asked about their parents’ education, four of their mothers and seven of their fathers had not completed high school. Only seven of the mothers and three of the fathers had attended any post secondary education and only four of the parents had received a college degree.

Examination of student grades showed that the mean overall grade point average (GPA) for the two classes was 2.84 with no difference between the two classes. The mean overall science score for these students was 80.83 with a mean of 79.56 in the
environmental science course at the time of the intervention. For seventeen of the students, environmental science was their fourth science course.

Inspection of available student scores on the Louisiana Graduation Exit Exam (GEE) revealed that of the eighteen students who had taken the exam, eight had achieved basic or above, five approaching basic and five unsatisfactory. Though not included in the survey, the teacher revealed that 23 of the students were taking the class to meet their science requirement while the other two were taking the class strictly because of an interest in science.

**Instructor.** The environmental science teacher that participated in the research has taught biology, environmental science and earth science at the research site for the past seven years. She has also participated in informal education through teaching marine biology to high school students in the summer in the Florida Keys. She has been selected as teacher of the year at the research site and has received the prestigious Milken Award for outstanding teachers.

Her educational background includes a B.S. in Biology and is currently pursuing a Masters degree in Science Education. Just after the conclusion of this research, she received National Board Certification in Science Education. Her teaching preference is Environmental Science, and she consistently involves students through instructional activities such as water quality analysis. She has been the recipient of a number of instructional grants including the Michael Jordan grant for two years.

In completing the survey instrument shown in Appendix V, the teacher indicated that she normally used a wide variety of teaching techniques and instructional tools to promote student learning. Her reasons for changing her instructional strategies were to
improve student growth and to improve assessment scores. Her interest in professional improvement was to better meet the needs of the students.

**Student and Teacher Interviews**

During the research period, six of the students were interviewed on days 1, 6 and 10 using the interview guide in Appendix V. Three students were chosen from each class. An effort was made to select a high, average and low achieving student from each class. However, selection also depended on willingness to participate and ability to attend interview sessions. Interviews were conducted individually, tape recorded and lasted from 10 to 15 minutes.

**First Student Interview.** The initial interview occurred prior to the onset of the intervention. In the initial interview all students identified their environment as “everything that surrounds us” and most understood that the environment included both the living and nonliving. All felt that it was important to protect the environment but were rather vague on why we should protect the environment. One student suggested that we needed to “protected from the sun” while another suggested that we needed to “protect the environment for the future.” The students rather confidently felt that what we were trying to protect was the earth, “its natural wonders” and “the habitats, trees and forest.”

It was strongly evident that their beliefs about the environment had been greatly influenced by teachers. Three of the six interviewees indicated that their current environmental science teacher had greatly affected their beliefs about the environment while one of the other three was concerned about the extinction of rare animals. When asked what was the most important environmental issue of the present day society, four of the six students felt that pollution was the greatest concern while another student felt
that the greatest problems was that “people did not care for the environment” and the last student felt that fossil fuel usage was the greatest concern.

Second Student Interview. The same six students participated in the second interview. These interviews were conducted during intervals throughout the day on the sixth day of the intervention. During this interview, the students were asked how thing were going so far. Most of the students felt that it was going well though one felt that the activities were “boring.” One admitted that the initial work seemed “slow” but found the “outside activities interesting.” When probed, this student indicated that he found the tree corer to be fun to use.

In response to “what have you learned so far?” the students indicated that they had learned “some new things about testing trees,” “what dendrochronology is” and “how to age a tree.” One student responded that “air pollution could affect tree growth.”

When asked about their reaction to dendrochronology, four of the students responded enthusiastically with comments such as “it is exciting”, “I was totally shocked, I had no idea how much fun learning about trees could be,” “it was enjoyable,” and “it was a great learning experience.” One was glad to have “made it through this section.” When questioned about the remark, the student admitted that she had struggled with the roundhouse diagram but had finally figured it out.

The student who had considered the activities “boring” had gotten “nothing” from the activities. When probed, the student confessed that she “didn’t like science and math” and that she thought they should have more activities where they drew (referring to the tree cross sectional diagrams.) Later interviews with the teacher indicated that this student’s average was one of the lowest in the class and review of student academic
standings reflected that the child had not yet passed the Louisiana GEE for science and had repeated both Algebra I and biology before passing, indicating that the student had difficulty with both mathematics and science concepts.

In trying to identify activities that the students had enjoyed up to the fifth day, two students specified that they enjoyed using the computers to research the greenhouse effect, one enjoyed the tree ring diagrams, and two enjoyed the tree core sampling while the sixth still professed to having “not liked any of them.”

The students initially had no suggestions for improvements but when probed one suggested that there could be more hands on activities, another thought that the Webquest could have been shorter and another felt that better directions on the roundhouse diagram would have been helpful.

At this point the overall impression of the interviewed students was that the unit had not made a great impact on their lives so far but that they had “improved their knowledge” and that for one of them the unit “had made me more of a nature guy.”

Third Student Interview. During the third interview students were again asked to respond to how they felt about protecting the environment. Their response this time was more specific. Rather than vague comments such as the environment needs “protected from the sun” and that we needed to “protect the environment for the future,” responses included comments such as “I need to do a better job,” “the environment is very polluted,” “please protect it!,” and “we should use our resources respectfully.” One student now felt that the environment should be protected because “it could be a life or death situation some day.”
When again asked about the most important environmental problems, students were still concerned with pollution but now had refined their opinions to include climate change, global warming and fossil fuels. Though these six students did not indicate that they felt that the unit had greatly impacted their lives, they did relate that they had gained more knowledge about the environment, trees, pollution and global warming.

At the end of the intervention, all six students interviewed signified that the part of the unit that they enjoyed most was designing their own experiments and when asked how their friends felt about the unit they responded that most of the students enjoyed it. One aspect of the unit that all six students expressed a liking for was that they were the ones most involved with the activities and that the teacher “didn’t lecture a lot.”

Teacher Interview. Other than the initial survey instrument that the teacher completed, interviews between the teacher and researcher were more informal and consisted of frequent, short discussions during the time period of the intervention between class changes, before and after school. Comments made were recorded in the researcher log and reflected how the teacher felt the lessons were going, areas that needed clarification and the general demeanor of the students.

These interactions led to some slight modifications of the research during the time frame of the intervention but also gave insight into how the research was progressing and student performance and clarified what could be expected from the student work. Examples of these comments included:

“The students really liked the webquest but had a hard time finding the answers to some of the questions.”
“At first the students were really frustrated with the roundhouse diagrams but when a couple of them got the hang of it, they helped the rest. It was new to me too, so that didn’t help me help them. They really help the kids organize their ideas. I will use them again.”

“We really had a good time with looking at the tree rings with the Scope-on-a-Rope! It works best to use the 1-x lens on the big screen TV. Many of the kids went back and recounted their rings when we got the scope out.”

“The students liked using the corer. They commented that they didn’t know that you could find out how old a tree was without cutting the tree down.”

“These students will not do any homework. If they can’t get it done in class, they won’t do it. I am going to have to get them complete the experiments in school. I am afraid that their presentations will not show what all they actually learned.”

**Webquest and Roundhouse Diagrams**

The first activity after the pretest was the Webquest, which can be found in the Unit Plan in Appendix U. A sample of the student responses to this Webquest is included in Appendix Y and show that the students had correctly identified the mechanics of the greenhouse effect, found out what ozone was and had an understanding of carbon sequestration.

Students were then asked to complete a Roundhouse diagram to show their understanding of this activity. This activity was quantitatively evaluated by the rubric shown in Appendix Z. A sample diagram is included in Appendix Y. Highest possible score on the rubric was 45 points. In order to compare the scores of different students, if
sequencing was not applicable to a diagram, the sequencing component was eliminated and the score was adjusted to 45 points using proportions.

The researcher and teacher independently scored the Roundhouse diagram activity and looked for evidence that the students understood the concepts of the greenhouse effect, influences of greenhouse effect on climate and the impact of climate on living organisms. The reported values are the averages of both raters and reflect an interrater reliability coefficient of 0.936 as calculated by Pearson’s coefficient, indicating that the raters’ scoring was quite consistent. This may reflect the fact that the researcher and instructor have worked together for 7 years and have had frequent discussions on evaluating various activities. The highest score achieved on the diagrams was a 44, whereas the mean was 32 and the low was 17. The roundhouse diagrams reflected that the Webquest had provided the students with background information that described the growing concern over the greenhouse effect.

The teacher, in her journal, indicated that the Webquest required an entire class period to complete and that students needed additional time the next day to complete the Roundhouse diagrams. She commented that the students were frustrated with the activity to begin with because it was new to them but that they actually seemed to enjoy it. She noted that the students that understood it first were instrumental in helping the others figure it out.

In discussing the activity in their journals there were mixed reactions to the activity with strong evidence that none of the students had constructed Roundhouse diagrams before. Comments in their journals revealed that the students were almost equally divided into those that liked the diagrams and those that did not. Reasons for
disliking the Roundhouse diagrams were mostly because “I didn’t understand it” and “it made me think” though one student specified that he did not like it because “it was elementary.” Explanations for why students liked the activity included “because I got to draw,” and “it made me connect with the problems of the environment.” One student indicated that “I liked the Roundhouse diagram even though I had to think.”

**Cross-sectional Comparisons**

In this activity, students were introduced to dendrochronology by examining cross sections of a hickory tree over 100 years old and a pine that was considerably larger but younger. After class discussion on why this might be, students were provided with cross sections of both a gymnosperm and angiosperm and were asked to draw diagrams of each. Scope-on-a-Rope handheld microscopes were available to examine the rings. A sample of the student diagrams are shown in Appendix Y.

The teacher and researcher developed a rubric that allowed them to evaluate the diagrams for accuracy of the drawing, correct labeling of the diagram, evidence that the student could distinguish an angiosperm and gymnosperm. Features that the students were to include in the diagram are shown in the model diagram in Appendix AA. Rubrics were scored independently by the researcher and teacher and recorded as the average of the two. Interrater reliability of the instrument was calculated as 0.894. Four of the students achieved the maximum points possible for the activity while one student received only 10 points. The average was 23 points out of a possible 30 points.

Student journal responses to this particular activity showed that they really enjoyed using the Scope-on-a-Rope. One student’s response was “I liked the lab because we got to use cool magnifying glasses.” This was corroborated by the teacher’s journal in
which she commented that some of the students even recounted their tree rings with microscope to make sure they got the age right. She added that an end of class review showed that having the students draw the diagrams helped them remember the names of the parts.

Statistics and Climate Activity

In this activity students were provided with data for the precipitation and temperature averages for Louisiana since 1895 in both tabular and graph form. Using a dated tree “cookie,” students attempted to look for a relationship between climate and tree growth. Students measured each year’s growth using a metric ruler and tabulated the data by year. These were then incorporated into a multidimensional graph that displayed temperature, precipitation and annual growth.

A sample of a student graph is included in Appendix Y. Although the students did very well on this activity (average of 44 out of 50 with a range from 34 to 50) only a few actually enjoyed this activity. Comments in student journals included “I liked counting the tree rings but didn’t like the answer sheet,” “I liked making the graph but disliked interpreting it because it was stressful,” “I liked using the scope on the rope but did not like making the graphs because I hate making graphs,” “counting rings was monotonous,” “I learned that trees don’t actually grow according to the rainfall ” and “I didn’t like it because my tree cookie rings were very light which made it difficult to count.” Twenty-two of the students were correctly able to identify the factor (temperature or precipitation) that most affected the growth of their tree and could explain that there is a correspondence between tree growth and precipitation. Some students noticed that yearly temperature did not vary nearly as much as did precipitation.
However, the teacher indicated that she thought that “the students were frustrated with the activity because they had to learn material in a new way.” She also commented that the activity provided them with a chance to practice graphing skills which is a skill tested in a variety of standardized tests, and is a skill encompassed by both national and state standards in mathematics and science.

**Climate Change PowerPoint**

In this activity, students first viewed a CD of a PowerPoint developed by the researcher for this unit. Contents of the PowerPoint are presented in Appendix BB. To insure that the students comprehended the contents of the CD, they were asked to complete the reading guide in Appendix U that led them through the CD. After completing the reading guide, students engaged in the Climate Change Activities as presented by the Geological Society of America (Lewis, 2003).

The students complete the “Terrace Temperature” and “Tree Ring Climates” activities. The teacher’s response to this activity was: “PowerPoint has wonderful information on various methods of dating. ‘Tree Ring Climates’ is a good way to evaluate understanding of core samples before extracting some from trees. I liked the ‘Terrace Temperatures’ activity because of the charts and graphs that students must interpret. It is good to be exposed to these since they have them on the GEE and ACT. The students were frustrated with the two labs but I think it is because they have not had a lot of practice interpreting this kind of data.”

This frustration showed up in the students’ comments with remarks such as “I liked the PowerPoint but hated the activities.” More than 20 of the students remarked positively about the PowerPoint but negatively about the “worksheets.” This was evident
since most of the students scored 10 out of 10 on the reading guide but averaged 6 out of 9 on the tree ring activity and 8 out of 10 on the terrace temperature activity.

Inquiries

In days five through nine students learned to use a tree corer and designed and conducted research using trees as their research base. Student journals and interview comments revealed that students greatly enjoyed this aspect of the unit and learned something. Various journal comments that showed this included: “some pollutants can actually help a tree grow!,” “an unpolluted leaf has more stomata,” “trees grow at different rates” and “trees have little white spots when they are near pollution and that pollution can actually help trees.”

The teacher commented that “The students enjoyed the projects although some had problems with generating appropriate ideas to investigate. Most were excited to conduct the experiment. It certainly reinforced their knowledge of scientific method.”

Students were allowed to chose groups of four or five students and design their research. Vee diagrams forms were provided to direct their efforts. Since this was a first attempt to use Vee diagrams, many of these were sparse and needed guidance from the teacher.

After the research was completed, students presented their findings to the class and teacher on Day 10. These presentations were observed and recorded by the researcher. Presentations were rated with a rubric developed by the teacher and researcher (Appendix Z). The rubric was based on a rubric frequently used at the research site but was altered to fit the needs of this particular class. All student projects were evaluated independently by both the teacher and researcher. The interrater reliability
score for this rubric was 0.900. The average score on the experiments were 37 out of a maximum score of 50.

Scoring of the experiments revealed that areas of weakness in the experiment portion of the project were providing clear justification of the purpose of the experiment, sufficient replication, and ability to draw conclusions based on the evidence of the experiment. Ratings for these experiments are shown in Appendix CC.

Topics that the students chose to research included “Effect of Trees on Soil Chemistry,” “Are Polluted Leaves Different from Nonpolluted Leaves?,” “Does Sunlight Affect Tree Growth?,” “Do Trees Grow Better at the Bottom or Top of a Hill?,” “Does Competition Affect Tree Growth?” and “Does Species Affect Tree Growth?”

“Effects of Trees on Soil Chemistry.” In this experiment a group of five students analyzed soil at various intervals from the base of a live oak. They analyzed soil samples for color, texture, moisture, pH, nitrogen, potassium and phosphorus using a standard soil analysis kit. They hypothesized that soil analysis would show lower levels of each of the nutrients further away from the tree base. They chose to take samples at intervals of five, ten and thirty feet from the base of the tree. These students were aware that replication needed to be done but were only able to analyze one sample at each location. Evidence that showed that these students had really been interested in the experiment included comments such as “we needed to dig deeper before we took the sample,” “the darker soil was richer in nutrients” and “we needed to take more samples because there was a root right at the 10 foot sample and it had low nitrogen.” They concluded that they thought the tree “had a force on the nutrients” and that because of the root they really could not conclude whether distance from the tree affected soil nutrients.
“Are Polluted Leaves Different from Nonpolluted Leaves?” For this experiment, four students examined the affect of pollution on leaves. Students chose crepe myrtle trees in a nonpolluted area and an area where they felt that pollution would be greater. The polluted area that they chose was the area where buses dropped students off in the morning and picked them up in the afternoon. The buses generally sit there running for about fifteen minutes so the students felt that the crepe myrtles in this area would be more polluted than the other crepe myrtles on the campus.

Their hypothesis was that leaves from trees in a polluted area would have less stomata than those in a nonpolluted area. Students used the Scope-on-a-Rope and counted the stomata on eight leaves from the two sites selected. Their findings were that there were fewer stomata on the leaves from the polluted area than from the nonpolluted area.

During the presentation, these students chose to exhibit what the stomata looked like with the scope-on-a-rope. It was very evident that the students knew exactly what the stomata looked like and pointed out that “they look like little white dots.” There was evidence that they had researched what stomata did and told the class that the stomata “were holes in the leaves where gases were exchanged.” However, in the questioning session, the students were unable to identify what gases were being exchanged and showed considerable interest when the teacher reminded them of photosynthesis and respiration.

“Does Sunlight Affect Tree Growth?” A group of four students investigated the effects of sunlight on tree growth. They chose two water oak trees in different locations, one that grew in the shade and one that grew in the sunlight. Their hypothesis was that
trees in the sun would grow faster than those that grew in the shade. Using a tree corer, they took core samples from each tree and recorded the size of each ring. These were averaged for each tree. In discussing replication, they mentioned that the replication was the number of rings, however, they felt that their results would have been more accurate if they had examined multiple trees. They did state that they didn’t take any more samples because “it took forever to count the rings.” They added that “the scope-on-a-rope” “sure helped a lot.”

They found that the rings of the tree that grew in the shade were actually larger than the tree that grew in the sunlight. They professed surprise at this and mentioned that there could have been other factors that could have caused the difference in growth. Factors that they thought might explain the difference in growth included genetics of the tree, soil quality, and age of the tree.

“Do Trees Grow Better at the Bottom or Top of a Hill?” The four students participating in this experiment hypothesized that trees at the top of a hill would grow better than the ones at the bottom of the hill because they thought that the trees at the top of the hill might get more rainfall. For this experiment the students chose to examine water oaks and took two core samples from two trees at the top of a hill and two at the bottom of a hill.

They found that those at the bottom grew more as measured by the width of the rings and decided that the trees might get more rainfall there. When the teacher probed them on this, they realized that rainfall would probably not be that different from the top of the hill and the bottom but eventually explained that they figured that most of the rain from the top of the tree would run down to the bottom. When asked what other factors
might have caused the difference, they pointed out that “the trees might be different or the soil might be different and we probably needed to use more samples.” When asked what they meant with “the trees might be different” they clarified that “one might grow better like some people grow taller.”

“Does Competition Affect Tree Growth?” For this experiment, a group of four students investigated the effect of competition on tree growth through evaluating tree core samples from oak trees in a crowded area versus a tree that was standing alone. They hypothesized that a tree standing alone would grow faster.

They examined one tree that represented each site and removed tree core samples from each. Each annual ring was measured and the average was determined for each tree. They found that the tree ring growth was greater for the tree that was alone. These students noted that after listening to the other groups, they felt like they should have taken samples from more than two trees. They also noted that next time “we would probably want to check to see that the soil was similar for the sites.”

“Does Species Affect Tree Growth?” The four students in this group examined how species of tree affected tree growth. Their hypothesis was that pine trees grew faster than maple trees. They chose to examine the core samples from a maple and a pine and to use width of tree rings as evidence of tree growth. The trees chosen were found close together and were of similar heights. They found that the pine grew faster as measured by tree ring width. In presenting their experiment, the group showed in their poster that they had made strong efforts to make sure the samples were as similar as possible and did note that more samples would have made their data better. The interest that these students had was quite obvious. In addition to presenting tabular data, this group
included descriptive data to compare the trees by height, location and even noted that
“the maple had a hollow in it!”

Researcher Observations. It was interesting to note that each group fed off the
information from previous presenters. These students were quick to notice that
replication was something they should have done but had not. Considering that the
students completed these experiments in a time frame of five days, their presentations
were quite well done. However, it was evident that most of these students did not take
these projects home with them. Though there was evidence that the students had
incorporated ideas that they had learned in class such as pollution, how to measure tree
rings and how to average, it was also evident that most of the students had not done any
extra research to find out background information before setting up their experiment. In
discussing the presentations, the teacher noted, “these kids just won’t do work at home!”
Watching these presentations was enlightening. There was an obvious rapport between
the students and teacher and it was evident that the students wanted to do well.

Exit Slips

After the end of the presentations, students were asked to conclude the unit by
answering three questions as an exit slip. To the question “What do you remember most
about the dendrochronology unit?” Eleven of the students responded that they would
remember the experiment while nine referred to counting rings and three mentioned
pollution and global warming. The second question was “What do you feel you primarily
gained from this unit?” Twenty of the students noted that they had learned more about
the environment and felt that it needed to be protected. The third question was “Which
part of the unit did you find most valuable?” Nine of the students felt the experiment was
the most valuable, six referred to working with the tree rings, six felt the webquest was most valuable, while the remaining four had no opinion.

Pre- and Posttest

Pre- and Posttest Description. A copy of the pre- and posttest is provided in Appendices V and W. The test was constructed by the researcher and the participating teacher and was based on a final that the teacher had successfully used in previous classes. Items were designed to check each of the objectives of the unit and consisted of 22 multiple choice items, graph interpretation, short answer, diagram labeling and discussion. Maximum possible score for both the pre- and posttest was 40 points where 22 points came from the multiple choice questions and 18 from the free response questions. Each construct was tested with two multiple choice items and split between even numbered and odd numbered items. For the post test, the same items were used but were rearranged and had the answers scrambled using a test generator. For the free response answer questions, the diagrams were replaced with ones that looked different but conveyed the same ideas.

The test was piloted in two chemistry classes to determine split-half reliability using the Spearman-Brown procedure. Initial results of the Spearman-Brown coefficient provided a value of 0.731. Examination of the results indicated discrepancies in two items which were revised. The resulting pretest had a split-half reliability of 0.854 for the classes participating in the research. The posttest split-half reliability was calculated as 0.877. Since it is suggested that for research purposes the split-half reliability should be 0.50 or better (Ary, Jacobs & Razavieh, 1996), these values were considered acceptable. Other items were evaluated independently by the researcher and the teacher
using a rubric which they developed. Interrater reliability score for these items was 0.9124. The interrater reliability coefficient is quite high, reflecting the familiarity between the researcher and instructor on evaluation style.

**Pretest.** On the pretest, the average score was 9.52. This reflects an average score of 7.68 out of a maximum of 22 points on the multiple choice portion of the test. The free response portion of the test consisted of four questions worth a total of 18 points. On this portion the students averaged 1.84 points. This partially reflected that fact that very few students responded to the free response questions that involved items that addressed the greenhouse effect, the anatomy of gymnosperms and angiosperms, precision of instruments and statistical calculations. On the multiple choice portion, items related to climate and greenhouse gases were the ones most frequently answered correctly while those most frequently missed involved those dealing with tree anatomy and causes of global warming.

**Posttest.** On the posttest, the average score was 18.76. For multiple choice portion of the test the average score was 11.72 out of 22 points. This represents an improvement of four points on this portion of the test from the pretest to the post test. Scores averaged 7.04 points on the free response of the posttest, indicating an improvement of 5.20 points on this 18 point section of the test.

**Comparison of Test Scores.** The total average gain for the entire test was 9.42 points. While grades were still not stellar, this did represent a significant (p < .01) improvement on test scores. The areas that showed the greatest improvement were those in the free response portion of the test, though improvement was also gained in multiple choice questions dealing with the greenhouse effect and global warming. Loses were
actually seen in questions that dealt with nonrenewable resources. When mentioned to
the participating teacher, it was determined that the previous unit to the
dendrochronology unit had been on nonrenewable resources, which may indicate that the
concepts of nonrenewable resources were more strongly remembered during the pretest
rather than the posttest.

**Statistical Analysis of Scores.** These scores were analyzed using the Wilcoxon
matched-pair signed rank test. A table that shows the rankings of the pre- and posttests is
shown in Appendix DD. The null hypothesis for this research was that there was no
significant difference in the pre- and posttest scores. For this test the difference in the
students’ pretest and posttest scores are ranked from the least difference to the maximum
difference. The rankings are then assigned a sign according to whether there was an
improvement or loss in score. These are used to calculate the test statistic which had a
value of three. Since the critical value for a two-tailed test at a significance level of 0.01
was 68 for a sample size of 25, the test statistic of 3 represented a statistical difference in
the pre- and posttest at the 0.01 significance level.

Although there was a significant difference in the pre- and posttest scores for
these students, it was a little disappointing that the actual scores did not reflect any grades
that would have been considered “A’s.” The highest score on the posttest was 30 out 40
points, which reflects a percentage of 75%. When discussing this with the teacher, she
stated that she was not surprised, that many of the students rarely performed well on the
tests and that only a few were interested in studying. She said that her average test scores
were generally low “D’s” and that these were similar to the tests scores that the students
generally made in the class.
Summary

This research was an attempt to develop and assess the value of a unit on dendrochronology to teach environmental change to high school students. The resulting unit was a combination of constructivist type activities that led the students through the ideas of environmental and climate change. The visual nature of the tree rings seen in the cross sectional cuttings from trees provided students with a tangible idea that trees could grow differently and, in fact, could be affected by a variety of factors such as climate, pollution and soil type. The unit also provided opportunities for the students to become with factors that can change the environment and even the Earth and that these changes have been occurring for eons.

The null hypothesis that there was no statistical difference in the pre- and posttest scores was rejected since the test statistic with a value of three was less than the critical value of 68 for a two-tailed test (p < .01) using 25 matched pairs. This analysis of the pre- and posttests showed that the unit had been effective. This was supported by the qualitative data that showed that both the students and teacher felt that the unit was a success. Two comments made by the students that succinctly summarize their thoughts and this research were “Wow, I didn’t know that learning about trees could be fun!” and “Man, we need to take better care of the environment!”
Discussion and Conclusions

Teachers are always searching for ways to improve student participation, enthusiasm and learning. Few have time to thoroughly research and prepare for innovative units that can provide students with the opportunity to learn material in depth and keep them actively involved in the learning process. This research was an attempt to use a topic that would be interesting to the students to create a unit that addressed multiple standards and actively involved students in their own learning in a way that would promote meaningful learning. The result was a dendrochronology unit that was taught to juniors and seniors in two environmental science classes at a small rural school in Louisiana. To evaluate the research, four research questions were answered.

Research Question One

In answering the question “Can an in-depth experiential dendrochronology unit be designed that incorporates a number of national science standards?,” the researcher spent several months researching dendrochronology and national and state standards to develop a unit that addressed a number of state and science standards. The overall unit is described in Appendix U and the activities that were used are listed in Appendix EE and show the National Standards addressed, Louisiana State Standards addressed and how each component was evaluated. The result of the time spent was a unit that used constructivist ideas and provided a chance for the students to do science as scientists do science. Efforts were made to design the unit to have student actively involved to promote meaningful learning through making the learning personally meaningful as suggested by Mintze & Wandersee (1998). To do this, Roger Bybee’s Five E Model was used to direct instruction (Bybee, 1997) and metacognitive tools such as use of multiple
graphics as described by (Tufte, 1997) were utilized. According to the National Science Standards (National Research Council, 2000), inquiry should be incorporated into science instruction at all levels from kindergarten through high school, thus a major component of the unit was the design and completion of experiments to investigate the relationship of trees to their environment.

**Research Question Two**

In answering the question “What value does each component of the unit and the unit in toto add to student understanding of environmental change as measured by pre- and posttests issued to participants, interviews with teachers and students and anecdotal notes?” it was clear that the students had gained a better understanding of environmental change through a statistically significant increase (P < .01) in test scores that revealed a gain of 9.42 points out of 40 points, reflecting a pretest average of 9.52 and a posttest average of 18.72 which is an improvement of 197%. Though gains did not meet the ideal, they are consistent with other research. In New York, knowledge scores on the environment ranged from 34.9% to 64.8% for eleventh grade students of about the same age as the students participating in this project (Milbrath & Enright, 1992). Interviews with the teachers and students revealed that the value of the unit could not be entirely evaluated with pre- and posttest statistics. The teacher indicated that she felt that the students participated enthusiastically and student comments were generally favorable including comments such as “I wish we could do more experiments” and “going outside made learning fun.”
**Research Question Three**

To answer research question three, “Do student-constructed, small-multiple graphic representations of their own tree ring pattern data add value to student understanding of environmental change?” students were evaluated with rubrics on their tree diagrams that compared gymnosperms and angiosperms and on their multidimensional graphs that plotted growth, temperature and precipitation against year of age. The pre- and posttest score on the tree anatomy proportion of the test went from only a few students even attempting to answer the question to twenty of the students getting at least 3 of the eight possible points on this section. The teacher noted that having to draw the diagram caused the students to look more seriously and really scrutinize their tree cookies during this section of the intervention. Though some of the weaker students complained that this “was hard,” many of them admitted that they had learned from the activity in their journals.

These results concur with Zull (2002) who suggests that people can recall pictures easily that they have seen for only seconds and with the thoughts of Tufte (2001) who suggested that graphics provided a way to organize vast amounts of information into smaller visible units.

The conclusion that the students reached from graphing was that climate could affect tree growth. One student’s journal said “I really was surprised that the temperature didn’t change near as much as the precipitation.” The teacher lauded the graphing activity because of the need for practicing such skills for standardized tests and because it promoted higher order thinking.
Research Question Four

In answering the question, “Does a culminating investigation into the effects of environmental change on tree growth add appreciable value to the unit’s contribution to student understanding of environmental change?” the qualitative data supports the inclusion of inquiry investigations in science classes. The experiment created enthusiasm in student learning in students not normally interested in science. Since the completion of the unit at least 10 of the students greeted the researcher at various times with positive comments about the experiment such as “Are we going to do research like that in other classes?”

The weakest of the interviewed students commented that “school would be better if we did more experiments.” In her presentation, this particular student showed enthusiasm in learning and was excited to show us the stomata present on leaves using the Scope-on-a-Rope. Her comments during the presentation indicated that she had indeed researched the topic and acted as if she had taken a leading role in the experiment. The teacher’s comment was that this was the first time she had seen this child show leadership in class.

Evaluation of students via a rubric showed that students were correctly able to state a hypothesis and became aware that replication would improve the reliability of an experiment. Evidence that the students had a better understanding of environmental change on completion of the intervention was most apparent in student comments during the inquiry presentations through such statements as “I hadn’t thought about crowding affecting growth of a tree,” “I didn’t know that trees could improve the air” and “I didn’t know that trees might grow better because of pollution.”
Interviews with the students revealed that after the experiment they were much more aware of the trees and included comments about the trees as a part of the environment and how “we needed to protect the trees” and “maybe we should plant more trees back.”

**Conclusion**

This research indicates that students can be successfully engaged in experiential units such as this dendrochronology unit to promote a better understanding of environmental change. The visual nature of the tree rings from the annual growth of trees provided students with evidence that growth is variable and that environmental factors such as precipitation can cause these variations. Examination of the tree rings provided students with a visible means of remembering the differences in types of trees and allowed them to construct their own knowledge on how trees differed and what factors would affect how a tree grew.

In addition to the knowledge that the students gained in tree anatomy, they were also able to grow in their knowledge of what the current environmental problems are and in an understanding of what the greenhouse effect is and what global warming could mean to them personally.

One advantageous aspect of this unit is that of student involvement. The activities were designed in such a way that the teacher served more as a facilitator and less as a conveyor of knowledge. This allowed the students to develop understandings more closely fitting the ideas of the human constructivist in which the students were engaged in meaningful learning rather than rote learning.
One frequent issue in education is the evaluation of student achievement. Though objective tests are the norm, this unit allowed multiple means of assessment. These included the traditional objective test but also had components for student artifacts and inquiry investigations. These multiple assessment methods afforded a better chance of evaluating what the students had actually learned.

Though this research was conducted with high school students in a rural area, the unit that was developed has applications in other grade levels and for other parts of the country. The equipment needed was minimal and relatively inexpensive. All that was required was a tree corer, tree rings and either a Scope-on-a-Rope or another source of magnification. The topic is relevant to most parts of the country since annual tree rings are visible in some type of tree in all but the desert areas of the country. Since the tree rings are visible, even young children would be able to see the differences in growth from year to year.

Besides being very visible, another advantage of using dendrochronology as a teaching tool is that it can provide a number of different inquiry investigations that the students can develop. In this research all eight groups developed entirely different research projects that were easily implemented. Although these were on a short term basis and were rather small, other inquiry investigations could be more long term and could be investigated with greater depth.

This investigation and unit can be the adapted to other grade levels. Accommodating this unit for other age groups should be relatively easy. One could either lengthen or shorten the time span of the inquiry phase or conduct a whole group investigation rather than in small groups. Additionally, the depth of and the quantity of
information on global warming, climate change and the greenhouse effect can be adapted to the educational level. Similarly, the small multiple graphics activity, the Roundhouse diagram and the statistics and graphing activity can be modified to fit the needs of the students involved.

The frustration of the students in response to the graphing activity indicates that another area of research that might be warranted is the study of ways in which graphing techniques can be incorporated into science instruction. Investigations into factors that affect tree growth, examination of historical and natural data on environmental change in the atmosphere and analysis of climatic data would all provide opportunities for students to pursue information that would encourage the analysis and production of graphic data.

In conclusion, this study of the effectiveness of the use of dendrochronology as a means of improving student understanding of environmental change revealed that student understanding was improved by the implementation of the unit. Though these results were visible with the quantitative data, qualitative data demonstrated that student learning went beyond that visible with pen and paper test and revealed that students had a better understanding of what their environment was, how it was changing and what factors might affect these changes.
Literature Cited


Appendix A

Dendrochronology Overview Concept Map

Dendrochronology

- studies
  - age of trees
    - has branches
      - e.g. dendroecology
        - helps students study environmental issues
          - are influenced by environmental factors
  - by examining tree rings
    - provides visualization
      - inquiry
        - addresses metacognition
          - enhances scaffolding of learning
    - in scientific processes
      - e.g.
        - as suggested by human constructivism
          - which includes the learning cycle

- can promote meaningful learning
  - as suggested by learning theories
    - which includes metacognition
      - addresses scaffolding of learning
        - advocates
Appendix B

Research Vee Diagram of Investigation

**RESEARCH QUESTION:**

**SUBQUESTIONS**

1. Can a dendrochronology unit that has both depth and breadth be designed that incorporates a several of national science standards?

2. What value does each component of the unit and the unit in toto add to student understanding of environmental change as measured by pre and post tests issued to participants, interviews with teachers and students and anecdotal notes?

3. Does a culminating investigation into the effects of environmental change on tree growth add appreciable value to the unit’s contribution to student understanding of environmental change?

4. Do student-constructed, small-multiple graphic representations of their own tree ring pattern data add value to student understanding of environmental change?

**Value claims**

Meaningful learning is improved through personal connection and active learning. Dendrochronology is an effective tool to help students understand environmental change.

**Knowledge claims**

Understanding of environmental change will be improved through use of dendrochronology to show the visual effects on tree ring growth. Students learn better when they can connect visually to the concepts that they are learning.

**Transformations**

Transcription and analysis of student interview tapes
Transcription and analysis of teacher interviews
Transcription and analysis of lesson videotapes
Descriptive and statistical analysis of pre and post tests
Analysis of student created artifacts

**Records**

Student concept maps, student vee diagrams, student graphics of tree ring records, student graphical representation of relationship of climate to tree ring growth, videotapes of selected lessons, audiotapes of student and teacher interviews, fieldnotes, pre and post tests, teacher and student questionnaires

**Theories**

Novak’s learning theory
Ausubel’s meaningful learning theory
Kolb’s learning cycle

**Principles**

Active student involvement improves retention of learning and creates stronger metacognitive structures. Environmental awareness and appreciation are prerequisites to environmental responsibility. Tree ring data provide a sound chronological record of past environmental events.

**Concepts**

Biodiversity, cambium, chronological record, dendrochronology, early growth, environmental change, environmental quality, late growth, lateral rays, limiting factor, phloem, small multiple graphics, tracheid, vessel cells, xylem

**Events**

Interviews, concept map co-construction, field notes, instructional activities, pre and post test, questionnaires
Appendix C

Learning Theories Concept Map

- Learning Theories include
  - Piaget
    - developed
    - cognitive structure theory
      - based
      - schema
        - to store
        - new knowledge
  - Bruner
    - designed
    - cognitive assimilation theory
      - developmental model
      - motivation
      - discovery-learning model
  - Ausubel
    - created
    - cognitive assimilation theory
      - centered on
        - prior knowledge
      - based on
        - six principles
          - e.g.
            - subsumption
  - Novak
    - established
    - human constructivist theory

- Appendix C

Learning Theories Concept Map

- assimilation
- accommodation
- equilibration

- must reach
- added by
- changed by
Appendix D

Metacognition Concept Map

- Metacognition
  - Requires
    - Tools
      - E.g. vee diagrams
    - E.g. concept maps
  - Requires
    - Active learners
      - To evaluate
        - Teachers
        - Ideas
    - Long-term learning
      - About
    - Thinking
      - Thinking
  - Promoted by
    - Scaffolding
      - Of
        - New concepts
          - To
            - Old concepts
              - Meaning
Appendix E

Human Constructivist Theory

human constructivist theory

developed by
Novak

concerned with
meaningful learning

depends on
scaffolding of learning

must be

works with

knowledge

organization of thoughts

prior knowledge

introduced

concept maps

educational theorist

identified

misconceptions

assesses

knowledge

science education

built on

theories

e.g.

Ausubel

Bruner

depends on

prior knowledge

science education

e.g.

organization of thoughts

that shows

subsumes
Appendix F

Brain Concept Map

brain

includes
- research
  improved by
technologies
  e.g.
electroencephalograph
e.g.
fMRI
e.g.
OIS

is the seat of
- learning
  requires
  communication
  involves
  transformations
  of
temporal cortex
  with
prefrontal cortex

promotes
memory
integrative cortex

has
unlimited capacity

for
images
serve as
teaching tool
through using
graphics
Appendix G
Visualization Concept Map
Appendix H

Inquiry Concept Map

- Inquiry
  - is essential component of science education
    - advocated by science educators
    - that belong to NRC
      - promotes higher order thinking skills
        - in agreement with
          - in agreement with
            - in agreement with NRC

- Inquiry
  - requires active involvement to answer students’ questions
    - urged by Dewey
      - pioneered by Dewey
        - developed by student
          - has components
            - e.g. observing
            - e.g. gathering
            - e.g. communicating
Appendix I

Assessment Concept Map

- Assessment
  - drives
    - No Child Left Behind uses
      - student progress to determine
      - school accountability
  - greatly influenced by
    - Tyler evaluated
      - programs curriculum students
  - in its normal form has been
    - pen and paper may be
      - criterion referenced in the form of
        - classroom evaluation
      - norm referenced e.g.
        - IOWA
  - alternative forms that include
    - Vee diagrams
    - student inquiries
    - concept maps
    - student creations

- No Child Left Behind
- student progress
- school accountability
- Tyler
- classroom evaluation
- IOWA
Appendix J

Concept Mapping Concept Map

- **Concept mapping**
  - encourages
  - related to
  - organizes
  - may serve as
    - assessment
  - is
    - visual representation
      - for
      - of
    - e.g.
      - misconceptions
      - knowledge
        - long term knowing
  - new ideas
  - scaffolding
  - by increasing
    - mindful learning
  - transfer of learning
    - by providing
      - thought
  - by recognizing
    - misconceptions
      - photosynthesis

- **Concept mapping**
  - for
  - of
  - to
    - prior knowledge
  - of
    - new ideas
  - of
    - misconceptions
Appendix K

Environmental Issues Concept Map

Environmental Issues

- includes
  - local issues
    - may be
    - caused by
      - air quality
        - pollution
    - may involve
      - land use
- may be
- global
  - involving
    - natural resources
  - includes
    - biodiversity
- caused
  - greenhouse effect
    - as seen in
      - crude oil reserves
      - alternative sources
    - in decreasing
      - natural
        - volcanism
      - human impact
        - fossil fuels use
    - in establishing
      - e.g.,
      - e.g.,
      - e.g.,
Appendix L

Measuring Time Concept Map

- Measuring time
  - can be
    - macroscale
      - to examine
        - paleontology
          - to evaluate
            - archeological uses
              - differentiate
                - past civilizations
                  - to date
                  - artifacts
          - to date
            - past catastrophic events
              - caused by
                - geophysical factors
                  - dated by
                    - coral reef
                      - carbon 14
                    - ice core samples
                      - sediment
                    - dendrochronology
              - e.g.
                - atomic clock
                  - e.g.
                    - hours
            - conventional scale
              - understood as
                - microscale
                  - e.g.
                    - as evidenced
                      - paleoclimates
                        - to examine
                          - conventional scale
                            - understood as
                              - macroscale
                                - to examine
                                  - paleontology
                                    - to evaluate
                                      - archeological uses
                                          - differentiate
                                            - past civilizations
                                              - to date
                                              - artifacts
Appendix M

Environmental Education Concept Map

- Environmental Education
  - examines global problems
    - e.g. global warming
    - pollution
  - addresses local problems
    - e.g.
  - involves multiple instructional activities
    - may include inquiry
  - uses alternative assessments
    - requires student products
    - promote metacognition
  - should be multidiscipline
    - to include social issues
    - metacognition
  - has common goals
    - which include awareness
    - skills development
    - commitment
Appendix N

Dendrochronology History Concept Map

Dendrochronology

- is defined as examination of tree rings
- developed by Andrew Ellicott Douglass
- to relate to tree rings
- to determine age
- natural records that include vegetation growth
- of sunspot activity
- for evaluating environmental changes
- e.g. record of climatic changes
- e.g. natural disasters
- valuable tool in archaeology
- to age wooden artifacts
Appendix O

Trees Used in Dendrochronology Concept Map

Trees used in dendrochronology

do not include

tropical regions

e.g. rain forest

have no clear growth patterns
to differentiate

annual growth

are found in temperate zones

may use conifers

distinguished from hardwoods

distinguished by lateral rays

distinguished by readable growth rings

also have vessel cells

have analogous to

consists of tracheids

produce sap

Note: The diagram shows the use of trees in dendrochronology, distinguishing between tropical regions and temperate zones, with specific examples given for each category. The text provides a structured comparison between coniferous and non-coniferous trees, highlighting differences in growth patterns and anatomical features.

148
Appendix P

Tree Anatomy Concept Map

develops from cambium gives rise to phloem generates vascular tissue

cannot provide bark nutrients that represent rapid growth indicative of good growing conditions

classes of xylem transports water e.g. heartwood e.g. sapwood

consists of bands light wood

provide chronological record of

distinguished from dark wood of
closely packed cells
Appendix Q

Sample Preparation Concept Map

Dendrochronology sample preparation

- may include
  - archeological samples
    - which are best from
      - old timbers
    - may use
      - charcoal
  - may use
    - 5 mm cylinders
      - cut into cross sections
      - undergo multiple procedures
        - to emphasize variations in yearly patterns
        - from live trees
          - extracted with a tree borer
            - from old construction
              - found in old timbers
                - can date artifacts
                  - e.g. Stradivari violins
                    - compared to known tree chronologies

- can come from trees
  - charcoal
    - may be
      - 5 mm cylinders
        - cut into cross sections
        - undergo multiple procedures
          - to emphasize variations in yearly patterns
          - from live trees
            - extracted with a tree borer
              - from old construction
                - found in old timbers
                  - can date artifacts
                    - e.g. Stradivari violins
                      - compared to known tree chronologies
Appendix R

Flow Chart of Research

Research Study (Fall, 2006)

consent form
pretest

intervention

multiple graphics
tree ring activities

roundhouse diagram
webquest
vee diagram

experiment design and completion

Post research activities

reflection writing
climate graphs

presentation at miniconference

post test
interviews

surveys (teacher and student)
Appendix S

Research Timeline

Research on literature, acquisition and development of instructional materials, and preparation of tree cookies (2003-2006)

Development of dendrochronology unit (2004-2006)

Pilot Study
Spring & Summer, 2006

Attainment of IRB certification (Fall, 2006) 
Prospectus preparation (2005 - 2006)

Presentation of Prospectus (Fall, 2006)

Research Study 
Fall, 2006)

Research Analysis 
(Fall 2006-Spring, 2007)
Appendix T
IRB Form and Consent Letter

IRB #: 3415  LSU Proposal #:__  Revised: 06/16/2006

LSU INSTITUTIONAL REVIEW BOARD (IRB) for
HUMAN RESEARCH SUBJECT PROTECTION

APPLICATION FOR EXEMPTION FROM INSTITUTIONAL OVERSIGHT

Unless they are qualified as meeting the specific criteria for exemption from Institutional Review Board (IRB) oversight, ALL LSU research/projects using living humans as subjects, or samples or data obtained from humans, directly or indirectly, with or without their consent, must be approved or exempted in advance by the LSU IRB. This Form helps the PI determine if a project may be exempted, and is used to request an exemption.

Instructions: Complete this form.

Exemption Applicant: If it appears that your study qualifies for exemption send:

(A) Two copies of this completed form,
(B) a brief project description (adequate to evaluate risks to subjects and to explain your responses to Parts A & B),
(C) copies of all instruments to be used. If this proposal is part of a grant proposal include a copy of the proposal and all recruitment material.
(D) the consent form that you will use in the study. A Waiver of Written Informed Consent is attached and must be completed only if you do not intend to have a signed consent form.
(E) Certificate of Completion of Human Subjects Protection Training for all personnel involved in the project (including students who are involved with testing or handling data) at http://cme.cancer.gov/clinicaltrials/learning/humanparticipant-protections.asp. (Unless already on file with the IRB.)

to: ONE screening committee member (listed at the end of this form) in the most closely related department/discipline or to IRB office.

If exemption seems likely, submit it. If not, submit regular IRB application. Help is available from Dr. Robert Mathews, 578-8692, irb@lsu.edu or any screening committee member.

Principal Investigator ___ Cynthia McCormick ___  Student? ___ yes ___ Y/N
Ph: ___ 985-639-6812 ___  E-mail: cmccor2@lsu.edu  Dept/Unit: Curriculum and Instruction

If Student, name supervising professor ___ Dr. ___ James Wandersee ___  Ph: ___ 225/ 578-6867 ___
Mailing Address ___ 41034 Highway 16 Franklinton, LA 70438 ___ Ph ___ 985-639-6312 ___
Project Title Using Dendrochronology to Understand Environmental Change
Agency expected to fund project
Subject pool (e.g. Psychology Students) Science students at Franklinton High School

Circle any “vulnerable populations to be used: (children <18; the mentally impaired, pregnant women, the aged, other). Projects with incarcerated persons cannot be exempted.

I certify my responses are accurate and complete. If the project scope or design is later changed I will resubmit for review. I will obtain written approval from the Authorized Representative of all non-LSU institutions in which the study is conducted.

PI Signature ___ ___ Date 9/26/06 (no per signatures)

Screening Committee Action: Exempted V  Not Exempted ___ Category/Paragraph
Reviewer ___ Kristin Ganse ___ Signature ___ Date 09-21-2006

Study exempted by
Louisiana State University
Institutional Review Board
203 B-1 David Boyd Hall
225-578-8692
Part A: DETERMINATION OF "RESEARCH" and POTENTIAL FOR RISK

This section determines whether the project meets the Department of Health and Human Services (HSS) definition of research involving human subjects, and if not, whether it nevertheless presents more than "minimal risk" to human subjects that makes IRB review prudent and necessary.

1. Is the project involving human subjects a systematic investigation, including research, development, testing, or evaluation, designed to develop or contribute to generalizable knowledge?
   (Note some instructional development and service programs will include a "research" component that may fall within HSS' definition of human subject research).

   □ YES

   □ NO

2. Does the project present physical, psychological, social or legal risks to the participants reasonably expected to exceed those risks normally experienced in daily life or in routine diagnostic physical or psychological examination or testing? You must consider the consequences if individual data inadvertently become public.

   □ YES  Stop. This research cannot be exempted—submit application for IRB review.

   □ NO Continue to see if research can be exempted from IRB oversight.

3. Are any of your participants incarcerated?

   □ YES  Stop. This research cannot be exempted—submit application for IRB review.

   □ NO Continue to see if research can be exempted from IRB oversight.

4. Are you obtaining any health information from a health care provider that contains any of the identifiers listed below?
   A. Names
   B. Address: street address, city, county, precinct, ZIP code, and their equivalent geocodes. Exception for ZIP codes: The initial three digits of the ZIP Code may be used, if according to current publicly available data from the Bureau of the Census, (1) The geographic unit formed by combining all ZIP codes with the same three initial digits contains more than 20,000 people; and (2) the initial three digits of a ZIP code for all such geographic units containing 20,000 or fewer people is changed to '000'. (Note: The 17 currently restricted 3-digit ZIP codes to be replaced with '000' include: 036, 059, 063, 102, 203, 556, 692, 790, 821, 823, 830, 831, 878, 879, 884, 890, and 893.)
   C. Dates related to individuals
      i. Birth date
      ii. Admission date
      iii. Discharge date
      iv. Date of death
      v. And all ages over 89 and all elements of dates (including year) indicative of such age. Such ages and elements may be aggregated into a single category of age 90 or older.
   D. Telephone numbers;
E. Fax numbers;
F. Electronic mail addresses;
G. Social security numbers;
H. Medical record numbers; (including prescription numbers and clinical trial numbers)
I. Health plan beneficiary numbers;
J. Account numbers;
K. Certificate/license numbers;
L. Vehicle identifiers and serial numbers including license plate numbers;
M. Device identifiers and serial numbers;
N. Web Universal Resource Locators (URLs);
O. Internet Protocol (IP) address numbers;
P. Biometric identifiers, including finger and voice prints;
Q. Full face photographic images and any comparable images; and
R. Any other unique identifying number, characteristic, or code; except a code used for re-identification purposes; and
S. The facility does not have actual knowledge that the information could be used alone or in combination with other information to identify an individual who is the subject of the information.

☐ YES Stop. This research cannot be exempted–submit application for IRB review.
☒ NO Continue to see if research can be exempted from IRB oversight.

Part B: EXEMPTION CRITERIA FOR RESEARCH PROJECTS

Research is exemptable when all research methods are one or more of the following five categories. Check statements that apply to your study:

☒ 1. In education setting, research to evaluate normal educational practices.

☐ 2. For research not involving vulnerable people (prisoner, fetus, pregnancy, children, or mentally impaired): observe public behavior (including participatory observation), or do interviews or surveys or educational tests:

The research must also comply with one of the following: either that

☒ a) the participants cannot be identified, directly or statistically;

☐ or that

☒ b) the responses/observations could not harm participants if made public;

☐ or that

c) federal statute(s) completely protect all participants' confidentiality;

or that

3. For research not involving vulnerable people (prisoner, fetus, pregnancy, children, or mentally impaired): observe public behavior (including participatory observation), or do interviews or surveys or educational tests:
   - all respondents are elected, appointed, or candidates for public officials.

4. Uses only existing data, documents, records, or specimens properly obtained.

The research must also comply with one of the following:

either that:
   a) subjects cannot be identified in the research data
directly or statistically, and no-one can trace back from research data to identify a participant;

or that

b) the sources are publicly available

5. Research or demonstration service/care programs, e.g. health care delivery.

The research must also comply with all of the following:

a) it is directly conducted or approved by the head of a US Govt. department or agency.

and that

b) it concerns only issues under usual administrative
   control (48 Fed Reg 5268-9), e.g., regulations, eligibility, services, or delivery systems;

and that

c) its research/evaluation methods are also exempt from IRB review.

6. For research not involving vulnerable volunteers [see “2 & 3” above], do food research to evaluate quality, taste, or consumer acceptance.

The research must also comply with one of the following:

either that:
   a) the food has no additives;

or that

b) the food is certified safe by the USDA, FDA, or EPA.

NOTE: Copies of your IRB stamped consent form must be used in obtaining consent. Even when exempted, the researcher is required to exercise prudence in protecting the interests of research subjects, obtain informed consent if appropriate, and must conform to the Ethical Principles and Guidelines for the Protection of Human Subjects (Belmont Report), 45 CFR 46, and LSU Guide to Informed Consent; (Available from OSP or http://www.lsu.edu/itb)
HUMAN SUBJECTS SCREENING COMMITTEE MEMBERS can assist & review:

<table>
<thead>
<tr>
<th>COLLEGE OF ARTS AND SCIENCES:</th>
<th>MASS COMMUN/SOC WK/AG:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Noell * (Psych) 578-4119</td>
<td>Dr. Nelson (Mass C) 578-6686</td>
</tr>
<tr>
<td>Dr. Geiselman * (Psych) 763-2695</td>
<td>Dr. Archambeault(Soc Wk) 8-1374</td>
</tr>
<tr>
<td>Dr. Beggs (Socio) 578-1119</td>
<td>Dr. Keenan* (Hum Ecoi) 578-1708</td>
</tr>
<tr>
<td>Dr. Honeycutt(Comm.Stu.) 578-6676</td>
<td>Dr. Belleau (Hum Ecoi) 578-1535</td>
</tr>
<tr>
<td>Dr. Dixit (Comm.Sc./Dis) 578-3938</td>
<td>Dr. Osborne (Mass C) 578-9296</td>
</tr>
<tr>
<td>Dr. Copeland* (Psych) 578-4117</td>
<td>Dr. Timothy F. Page (Soc Wk) 578-1358</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ED/LIBRARIES/INFO SCI</th>
<th>BUSINESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ms. Phillips (LSU Libraries) 578-6552</td>
<td>Dr. McKee (Marketing) 578-8788</td>
</tr>
<tr>
<td>Dr. Landin* (Kinesiol) 578-2916</td>
<td></td>
</tr>
<tr>
<td>Dr. MacGregor (ELRC) 578-2150</td>
<td></td>
</tr>
<tr>
<td>Dr. Gansle (Curric &amp; I) 578-7213</td>
<td></td>
</tr>
</tbody>
</table>

(* = IRB member)
Consent Form for Science Students

Title of Research Study
Use of Dendrochronology to Promote Understanding of Environmental Change

Project Director
Principle Investigator: Cynthia McCormick, Doctoral Candidate, LSU
41034 Highway 16, Franklinton, LA 70438
(985) 839-6312

Faculty Advisor: Dr. James H. Wandersee, Wm. LeBlanc Alumni Professor of Biology
Education
Louisiana State University
(225) 578-2348

Purpose of Research
The purpose of the study is to investigate how an experiential unit on dendrochronology will affect high school students’ understanding of environmental change.

Procedures of this Research
During a two-week period unit participants will participate in a unit on dendrochronology (analysis of tree rings). All participants will be administered a pre-instructional test and questionnaire related to dendrochronology, environmental change and science process skills. Student artifacts will be collected during the course of the unit to be evaluated for understanding. A comparable post test will also be administered after completion of the unit. Selected participants will co-construct concept maps with the researcher to evaluate their change in understanding of environmental change.

Potential Risks of Discomfort
There are no anticipated medical, personal, social, or academic risks associated with this study. Participation nor nonparticipation in the research will not penalize the participant’s grade. Participants with any concerns are encouraged to discuss them with the principal investigator.
Potential Benefits to You or Others

The study has the potential to benefit teachers and students of science by developing a unit to enhance environmental understanding and by furnishing evidence of the efficacy of dendrochronology as an instructional tool for environmental change. The students may gain a better understanding of climate change and environmental change.

Alternative Procedures
There are no alternative procedures in this research. Participants’ role in the study is strictly voluntary; participants may withdraw and terminate participation at any time without consequences.

Protection of Confidentiality
Confidentiality and anonymity are insured through numerical coding of all data. Any identification of materials will be under assumed names to ensure privacy. All data will be treated equitably and kept confidential. Results of the study will be made available in the campus library for any interested parties.
I have been fully informed of the above research study on dendrochronology with its possible benefits and risks and I give my permission for my child to participate in this study and understand that the investigator is obligated to provide me with a signed copy of this consent form. I also understand that if I have any questions on the subjects’ rights or have other concerns I may contact:

Robert C. Mathews, Chairman,
Institutional Review Board,
203 B-1 David Boyd Hall,
Louisiana State University,
Baton Rouge, LA, 70803
Phone Number (225)-578-8692

_________________________      ________________________  _________________
 (student name)    (parent signature)  (date)

I have been fully informed of the above research study on dendrochronology with its possible benefits and risks, and give my assent to participate in this study.

_________________________      ________________________  _________________
 (student name)    (student signature)  (date)

_________________________      ________________________  _________________
 (person obtaining consent)       (signature of consent obtainer)  (date)
Appendix U

Dendrochronology Unit

**Purpose of the unit:** To use dendrochronology to help high school students better understand environmental change.

**Unit length:** ten days

**Student assessment:** pre and post tests, student constructed small multiple graphics, student created graphs, student constructed and labeled diagrams, student round house diagrams, student calculations, student measurements

**Objectives:**

1. Compare the anatomy of angiosperm and gymnosperm trees based on cross sectional cuts.
2. Accurately measure annual tree growth for multiple tree cross sections.
3. Use class measurements to determine the statistics of mean, mode, median and standard error for average annual growth of a tree.
4. Recognize the degree of precision of various instruments for measuring length.
5. Relate climatic factors to variation in tree growth with graphical representation.
6. Recognize other environmental factors besides climate that can alter tree growth. (e.g. stand dynamics, catastrophic weather events, insect damage)
7. Identify regions of the anatomy of a tree cross section.
8. Define climate change.

9. Distinguish climate and weather.

10. Recognize the patterns that contribute to the Earth’s changing climate.

11. Draw a sketch of the mechanism of the greenhouse effect.

12. Identify the predominant gases responsible for the greenhouse effect.

13. Describe natural artifacts that scientists use to establish the timeline of past climatic conditions.

**National Science Education Standards**

Content Standard A:

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard C:

- Interdependence of organisms
- Matter, energy, and organization in living systems
- Behavior of organisms

Content Standard D:

- Energy in the earth system
- Geochemical cycles
- Origin and evolution of the earth system
Content Standard E:

- Understandings about science and technology

Content Standard F:

- Personal and community health
- Population growth
- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

Content Standard G:

- Science as a human endeavor
- Nature of scientific knowledge
- Historical perspectives

State Content Standards and Benchmarks

Inquiry

- Write a testable question or hypothesis when given a topic (SI-H-A1)
- Describe how investigations can be observation, description, literature survey, classification, or experimentation (SI-H-A2)
- Plan and record step-by-step procedures for a valid investigation, select equipment and materials, and identify variables and controls (SI-H-A2)
• Conduct an investigation that includes multiple trials and record, organize, and display data appropriately (SI-H-A2)

• Utilize mathematics, organizational tools, and graphing skills to solve problems (SI-H-A3)

• Use technology when appropriate to enhance laboratory investigations and presentations of findings (SI-H-A3)

• Choose appropriate models to explain scientific knowledge or experimental results (e.g., objects, mathematical relationships, plans, schemes, examples, role-playing, computer simulations) (SI-H-A4)

• Write and defend a conclusion based on logical analysis of experimental data (SI-H-A6) (SI-H-A2)

• Analyze the conclusion from an investigation by using data to determine its validity (SI-H-B4)

• Use the following rules of evidence to examine experimental results:
  (a) Can an expert's technique or theory be tested, has it been tested, or is it simply a subjective, conclusive approach that cannot be reasonably assessed for reliability?
  (b) Has the technique or theory been subjected to peer review and publication?
  (c) What is the known or potential rate of error of the technique or theory when applied?
  (d) Were standards and controls applied and maintained?
  (e) Has the technique or theory been generally accepted in the scientific community? (SI-H-B5) (SI-H-B1) (SI-H-B4)
Life Science

- Illustrate the flow of carbon, nitrogen, and water through an ecosystem (LS-H-D1)
- Compare structure to function of organs in a variety of organisms (LS-H-F1)
- Explain how selected organisms respond to a variety of stimuli (LS-H-F3)

Environmental Science

- Analyze the consequences of changes in selected divisions of the biosphere (e.g., ozone depletion, global warming, acid rain) (SE-H-A5) (SE-H-A7)
- Give examples and describe the effect of pollutants on selected populations (SE-H-A11)
- Cite and explain examples of organisms’ adaptations to environmental pressures over time (SE-H-A8)

Chemistry

- Measure and determine the physical quantities of an object or unknown sample using correct prefixes and metric system units (e.g., mass, charge, pressure, volume, temperature, density) (PS-H-A1)
- Determine and record measurements correctly using significant digits and scientific notation (PS-H-A1)
- Determine accuracy and precision of measured data (PS-H-A1)
- Measure the physical properties of different forms of matter in metric system units (e.g., length, mass, volume, temperature) (PS-H-A1)
- Gather and organize data in charts, tables, and graphs (PS-H-A1)
• Differentiate between accuracy and precision and evaluate percent error (PS-H-A1)

• Determine the significant figures based on precision of measurement for stated quantities (PS-H-A1)

**Day to Day Lesson Guide**

Day 1:

• Introduce unit on dendrochronology and environmental change by having students complete a KWL (know, want to know, learned) on what they know about environmental change.

• Complete webquest on climate change using Activity Sheet 1.

• Using information learned, have students construct roundhouse diagrams in pairs.

Day 2:

• Show the students cross sections of a hickory tree which is approximately 100 years old and a cross section of a pine that is approximately 50 years old. Show how the age of each is determined by counting growth rings. By telling them the date that the trees were felled, show them how they can count back to the year that they were born. Allow students time to comment on what they see in the cross section.

• Provide each student with a conifer and gymnosperm tree round, a labeled diagram of the different regions of a conifer and gymnosperm cross section, and have each student identify these in their sample. Allow time for students to age the sample and to use a “Scope on the Rope” to examine the cells more closely.

• Using available supplies, (colored pencils and sketch paper), have students draw and label the cross sections of the gymnosperm and the angiosperm.
Day 3:

- Using same tree rings as before, have students accurately measure and record by year the width of each ring. Provide background information on accuracy and precision, degree of error in measurement, and statistical calculations.
- Have students determine years of maximum and minimum growth and determine mean, median, mode and standard error.
- Have students develop graphs that show yearly growth for their sample, annual precipitation and annual temperature using available past annual temperature and rainfall data.
- Have students discuss whether they think there is a relationship between their sample’s growth and either temperature or precipitation.

Day 4:

- Using the researcher created PowerPoint of “Change over Time” introduce students to climate change over time. Have students complete the reading guide as they go through the PowerPoint.
- Have students complete either the Iceman activity, Tree ring activity and Terrace temperature activities based on the Climate Change CD by the Geological Society of America (Lewis & Tau Rho Alpha.)
- Discuss what students have learned. Help students relate what they have learned to tree ring data learned

Day 5:

- Demonstrate the use of a tree corer for extracting samples from trees. Explain how foresters use the data to determine past effects on the trees.
• Provide opportunities for students to extract and prepare samples for their own examination. Allow students to determine age of their samples and to observe and record any anomalies in their core samples.

Day 6 & 7:
• Have students design experiments in groups of 4 using either tree core samples that are available or samples that they obtain themselves. Provide Vee diagrams for students to design their experiment.

Day 8
• Create report on information using available computer sources

Day 9
• Present student information in the format of a “Miniconference” using poster sessions with opportunities for students to visit with each other on what they have learned. Provide rubrics for evaluation. Have students record one thing they learn from each presentation and provide one constructive criticism and one positive aspect of each.

Day 10
• Students write a reflection on what they have learned.
• Take post test.
Dendrochronology and Environmental Change Activity One

Research global warming and complete the following Webquest. Answer the questions below using the provided URL’s. With the information that you have learned, complete a Roundhouse Diagram.

http://www.ipcc.ch/present/COP65/bobwatson.ppt#430
http://www.epa.gov/ozone/science/process.html
http://yosemite.epa.gov/oar/globalwarming.nsf/content/climate.html
http://www.grida.no/climate/ipcc_tar/wg1/039.htm

1. Draw a sketch of the greenhouse effect. Label five components of the graph. Use arrows to show how the reflection of radiation occurs.

2. Why is the greenhouse effect increasing?

3. One expected result of the greenhouse effect is that the global climate will become warming. What else is expected to happen?

4. If the temperature increases, what global changes will probably occur? Give specific amounts of the expected changes.

5. List 5 ways to reduce carbon dioxide production.

6. What are some health risks of global warming. Describe each in detail.

7. Using the information that you have found construct a roundhouse diagram. In doing so, consider the following steps:
   a. What is the main idea?
   b. Create a title for your diagram using the terms “and” and “of.”
   c. Write down your reasons for constructing the diagram.
   d. Write down the seven main ideas of your topic.
   e. Paraphrase each of your ideas in one of the sections of the diagram.
   f. Draw a picture or icon that represents each “chunk” of the diagram.
Climate Change CD Reading Guide

1. What is weather?

2. How do weather and climate differ?

3. What factors can affect climate change?


5. Why have scientists concluded that there has been a climate change in recent history?


7. List ways in which climate change has been documented.

8. You are asked to evaluate climate change records for the last 6000 years. Which method would you choose: what are the advantages and limitations of this method: Choose at least 6 factors to consider such as cost, ease of use, availability, accuracy, and two more of your choice to explain why you chose this method.

9. Who is Charles Keeling? What did he do?

10. What information is provided in the “Koshland Science Museum” graph. Identify the time scale used, the parameters, measured and the units for each parameter. Describe the trend that shows up in the graph. How do the parameters relate to each other.
Appendix V

Survey Instruments

Teacher Interview Instrument

Part I

Please circle the number indicating the extent to which you have decreased or increased the use of each of the following since the No Child Left Behind Act

Legend for chart:
1 – never
2 – rarely
3 – once a semester
4 – once a month
5 – at least once a week

<table>
<thead>
<tr>
<th>Instructional Strategies</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Writing assignments</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Group projects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Text-book based assignments</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Discussion Groups</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Multiple-choice questions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Open-response questions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. True-false questions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Use of manipulatives</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Inquiry/Investigation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Problem-solving activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Work sheets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Lesson based on current events</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. Project-based assignments</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14. Creative/critical thinking questions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15. Role playing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16. Use of charts, webs and/or outlines</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17. Use of response journals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18. Use of portfolios</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19. Use of rubrics or scoring guides</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20. Use of exhibitions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Teaching Techniques

21. Interdisciplinary Instruction          1 2 3 4 5
22. Lecturing                            1 2 3 4 5
23. Modeling                             1 2 3 4 5
24. Cooperative learning/ group work     1 2 3 4 5
25. Collaborative/team teaching          1 2 3 4 5
26. Peer or cross-age tutoring           1 2 3 4 5
27. Facilitating/coaching                1 2 3 4 5

Instructional Materials and Tools

28. Textbooks                            1 2 3 4 5
29. Reference books                      1 2 3 4 5
30. Supplementary books                  1 2 3 4 5
31. Primary source material              1 2 3 4 5
32. Newspaper/ magazines                 1 2 3 4 5
33. Audiovisual materials                1 2 3 4 5
34. Lab equipment                        1 2 3 4 5
35. Calculators                          1 2 3 4 5
36. Computers/ educational software      1 2 3 4 5
37. Computers/internet and/or on-line research service 1 2 3 4 5
38. Manipulatives                        1 2 3 4 5
39. Maps/globes/atlases                  1 2 3 4 5
40. Visual aids (i.e.,posters, graphs)   1 2 3 4 5

Part II

Please circle the number indicating your responses to the statements below, using the following scale:

SD = Strongly Disagree
D = Disagree
U = Undecided
A = Agree
SA = Strongly Agree

Changes in my instructional practices have been influenced by the following:

41. Personal desire to make changes      SD D U A SA
42. Belief that such changes will benefit students  SD D U A SA
43. Changes in the types assessment used for school accountability  SD D U A SA
44. Interest in helping my school improve accountability scores  SD D U A SA
45. Interest in helping my students attain GEE scores that will allow them to graduate high school  SD D U A SA
46. Interest in avoiding sanctions at my school  SD D U A SA
47. Interactions with school principal(s)  SD  D  U  A  SA
48. Interactions with colleagues  SD  D  U  A  SA
49. Staff development in which I have participated  SD  D  U  A  SA
50. Interactions with parents  SD  D  U  A  SA

Part III

Please mark the responses that describe you.

51. Male ----- Female ----

52. Teaching Experiences

3 years or less
4- 12 years
13 - 19 years
20 - 27 years
28 years or more

53. Education (Please mark the highest level obtained)

Bachelor's Degree
Masters
Specialist
Doctorate

54. Teaching Assignment

English
Mathematics
Science
Social Studies
Other

55. Circle the predominant grade level taught. (circle only one.)

Ninth
Tenth
Eleventh
Twelfth

56. Are you National Board Certified? If so, in what area?
Interview Guide for Selected Students

First Interview

What is the environment? When you think about the environment, what do you think of?
Is it something we ought to protect?
Why? For whom or for what?
What are we trying to protect, exactly?
What has influenced your beliefs?
What would you say are the most important environmental problems in present-day society?
What do you think would be good solutions to these problems?

Second Interview

How is the class going so far?
Which new things did you learn?
What is your reaction to what you learned?
How do you like the activities? Do you have a favorite one so far?
Is there anything about the class that you would change?
Do you feel the class has impacted your life in any way so far?

Third Interview

After the unit, what would you say about protecting the environment?
Is the environment something we ought to protect? Why, for whom?
What would you say are the most important environmental problems in present-day society?
What do you think would be good solutions to these problems?
Have your views changed on this subject since our first interview? How? If yes, why do you think that is?
Did this unit have anything to do with this change?
How do you feel about the dendrochronology unit now?
What were your reasons for taking this course?
What do you remember most from the course?
Do you feel the unit helped you better understand environmental situations today?
What do you feel you primarily gained from this unit?
Did anything have a particular impact on you, even something very subtle?
What about any of your friends in the class? How did they like the unit?
Which part of the course did you find most valuable? Least valuable?
Student Survey

Please answer the following questions. Your answers will be kept confidential.

1. Are you Male or Female?

2. What is your age?

3. What is your race?

4. What is the highest level of education you have completed?

5. What is the highest level of education your mother has completed?

6. What is the highest level of education your father has completed?

7. What are your plans after high school?

8. How many science courses have you had in high school?

9. What is your GPA? What is your GPA in science?

10. What is your IOWA score in science?
Appendix W

Pretest

1. The part of a tree cross section responsible for new growth is
   a. Xylem
   b. Vessel cells
   c. Sapwood
   d. Cambium

2. Xylem is responsible for
   a. Water transport
   b. Nutrient transport
   c. Support
   d. New growth

3. Angiosperms contain _____________ but gymnosperms do not
   a. Lateral rays
   b. Resin deposits
   c. Xylem
   d. Phloem

4. The part of a tree cross section that can be found in a gymnosperm but not an angiosperm is
   a. Xylem
   b. Phloem
   c. Tracheids
   d. Vessel cells

5. A. E. Douglass used dendrochronology to
   a. Established patterns of Native American land usage
   b. Past snow fall patterns
   c. Past sunspot activity
   d. Time of European settlement in Arizona

6. Tree ring patterns will probably not be affected by
   a. Tree density
   b. Time of day
   c. Pollution
   d. Snowfall

7. Climate differs from weather in that
   a. Weather only concerns a continent
   b. Weather is the average of temperature only
   c. Climate is the average of weather over a long period of time
   d. Climate only concerns a given location

8. Weather is
   a. Day to day
   b. Over centuries
   c. Concerns precipitation only
   d. The average of climatic conditions
9. Climate is primarily determined by the interaction of the atmosphere and  
   a. Winds  
   b. Plants  
   c. The lithosphere  
   d. Oceans  
10. The interaction of the atmosphere with the _____ determines the climate  
   a. Winds  
   b. Plants  
   c. The lithosphere  
   d. Oceans  
11. A society that relies on nonrenewable resources is unstable because these resources a  
   a. Are easy to find  
   b. Will run out  
   c. Are expensive  
   d. Cannot be recycled.  
12. Increasing the use of hydroelectric, wind, and geothermal energy is one way of reducing industrial society’s use of  
   a. Iron ore  
   b. Vacant land  
   c. Technology  
   d. Fossil fuels  
13. Ice core samples, dendrochronology, and radioactive carbon dating have all been used to assess  
   a. Soil type  
   b. Past climatic records  
   c. Ocean tide patterns  
   d. Biodiversity of an ecosystem  
14. Past climatic records have been measured by  
   a. Tree length, ice core samples and fossil fuel use  
   b. River depths, dendrochronology and coral reefs  
   c. Coral reefs, ice core samples, radioactive dating, dendrochronology  
   d. Lake sediments, tree length, fossil fuel use, ocean tide patterns  
15. The ozone layer changes are  
   a. Constant  
   b. Vary by season  
   c. The same in all parts of the world  
   d. Is not related to pollution  
16. The effect of fluorocarbons on the ozone layer is  
   a. Diminishing  
   b. Increasing  
   c. Staying the same  
   d. Varies by year  
17. Natural causes of global warming include  
   a. Tidal patterns  
   b. Changes in the sun’s activities
c. Glacial meltings  
d. Reversals in the Earth’s polarity

18. Increase in global gases will probably  
   a. Not affect the climate  
   b. Change the pattern of El Nino  
   c. Lower the temperature  
   d. **Change both types and severity of weather conditions**

19. The gases contributing to the greenhouse effect do not include  
   a. methane  
   b. oxides of nitrogen and oxygen  
   c. **hydrogen gases**  
   d. water vapor

20. A gas that contributes to the greenhouse effect is  
   a. Helium  
   b. Nitrogen  
   c. **Carbon dioxide**  
   d. Oxygen

21. During the last 150 years, levels of atmospheric carbon dioxide have  
   a. **Increased**  
   b. Decreased  
   c. Remained the same  
   d. Increased and decreased every 20 years.

22. Atmospheric carbon dioxide  
   a. has remained constant throughout the Earth’s history  
   b. is decreasing  
   c. is directly related to oxygen consumption  
   d. **has changed most dramatically in the last 150 years**

23. Explain the following diagram of the greenhouse effect.

![Diagram of the Greenhouse Effect](image-url)
24. Label the following diagram of a cross section of a tree. Include xylem, phloem, cambium, lateral rays, latewood and early wood. Do you think it is a conifer or an angiosperm? Why?

25. Which of the following instruments is most precise? Why?

26. Students gathered the following information on the density of copper. The accepted value for the density of copper is 8.94g/cm$^3$. Determine the mean, mode and average of the following data. What is the percent error? Identify the maximum and minimum values.

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Density (g/cm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9.22</td>
</tr>
<tr>
<td>2</td>
<td>8.65</td>
</tr>
<tr>
<td>3</td>
<td>8.90</td>
</tr>
<tr>
<td>4</td>
<td>8.93</td>
</tr>
<tr>
<td>5</td>
<td>8.48</td>
</tr>
<tr>
<td>6</td>
<td>8.93</td>
</tr>
<tr>
<td>7</td>
<td>9.02</td>
</tr>
<tr>
<td>8</td>
<td>9.13</td>
</tr>
<tr>
<td>9</td>
<td>8.97</td>
</tr>
<tr>
<td>10</td>
<td>8.69</td>
</tr>
</tbody>
</table>

Maximum: 9.22  
Minimum: 8.48  
Average / Mean: 8.89  
Mode: 8.93  
Median: 8.93  
Percent error: \( \frac{(8.94 - 8.89)}{8.94} \times 100 = 0.56\% \)
Appendix X

Posttest

1. The part of a tree cross section responsible for new growth is
   a. Xylem
   b. Cambium
   c. Vessel cells
   d. Sapwood
2. Xylem is responsible for
   a. reproduction
   b. temperature control
   c. Water transport
   d. New growth
3. Angiosperms contain _____________ but gymnosperms do not
   a. Resin deposits
   b. Xylem
   c. Lateral rays
   d. Phloem
4. The part of a tree cross section that can be found in a gymnosperm but not an angiosperm is
   a. Vessel cells
   b. Xylem
   c. Phloem
   d. Tracheids
5. A. E. Douglass used dendrochronology to
   a. Past snow fall patterns
   b. Past sunspot activity
   c. Established patterns of Native American land usage
   d. Time of European settlement in Arizona
6. Tree ring patterns will probably not be affected by
   a. Tree density
   b. Longitude
   c. Pollution
   d. Snowfall
7. Weather is
   a. Day to day
   b. Over centuries
   c. Concerns precipitation only
   d. Concerns temperature only
8. Climate differs from weather in that
   a. Weather only concerns a continent
   b. Climate only concerns a given location
   c. Weather is the average of temperature only
   d. Climate is the average of weather over a long period of time
9. The interaction of the atmosphere with the _____ determines the climate
   a. Winds
   b. Plants
   c. Human population
   d. Oceans

10. Climate is primarily determined by the interaction of the atmosphere and
    a. Winds
    b. Oceans
    c. Plants
    d. Animals

11. A society that relies on nonrenewable resources is unstable because these resources
    a. Are easy to find
    b. Are expensive
    c. Will run out
    d. Cannot be recycled.

12. Increasing the use of hydroelectric, wind, and geothermal energy is one way of reducing industrial society’s use of
    a. Iron ore
    b. Fossil fuels
    c. Technology
    d. Vacant land

13. Ice core samples, dendrochronology, and radioactive carbon dating have all been used to assess
    a. Past climatic records
    b. Ocean tide patterns
    c. Soil type
    d. Biodiversity of an ecosystem

14. Past climatic records have been measured by
    a. Coral reefs, ice core samples, radioactive dating, dendrochronology
    b. Tree length, ice core samples and fossil fuel use
    c. River depths, dendrochronology and coral reefs
    d. Lake sediments, tree length, fossil fuel use, ocean tide patterns

15. Natural causes of global warming include
    a. Glacial meltings
    b. Tidal patterns
    c. Changes in the sun’s activities
    d. Reversals in the Earth’s polarity

16. Increase in global gases will probably
    a. Not affect the climate
    b. Change the pattern of El Nino
    c. Change both types and severity of weather conditions
    d. Lower the temperature
17. The effect of fluorocarbons on the ozone layer is
   a. Increasing
   b. Staying the same
   c. **Diminishing**
   d. Varies by year

18. The ozone layer changes are
   a. The same in all parts of the world
   b. Constant
   c. Is not related to pollution
   d. **Vary by season**

19. A gas that contributes to the greenhouse effect is
   a. Helium
   b. Nitrogen
   c. **Carbon dioxide**
   d. butane

20. The gases contributing to the greenhouse effect do not include
   a. methane
   b. oxides of nitrogen and oxygen
   c. water vapor
   d. **neon**

21. Atmospheric carbon dioxide
   a. has remained constant throughout the Earth’s history
   b. is directly related to oxygen consumption
   c. **has changed most dramatically in the last 150 years**
   d. is decreasing

22. During the last 150 years, levels of atmospheric carbon dioxide have
   a. Increased and decreased every 20 years.
   b. **Increased**
   c. Decreased
   d. Remained the same
23. Explain the following diagram of the greenhouse effect.

![Diagram of the Greenhouse Effect](http://www.epa.gov/air/airtrends/aqtrnd95/globwarm.html)

24. Label the following diagram of a cross section of a tree. Include cambium, earlywood, latewood, phloem, pith, ray cells (lateral rays), vessels, xylem. Do you think it is a conifer or an angiosperm? Because?

![Diagram of a Tree Cross Section](http://www.epa.gov/air/airtrends/aqtrnd95/globwarm.html)

1. pith
2. heartwood
3. lateral ray (ray cell)
4. latewood
5. early wood
6. xylem
7. cambium
8. phloem
25. Which of the following instruments is most precise? Why?

![Meters A and B](image)

http://regentsprep.org/Regents/biology/units/laboratory/measurement.cfm

26. Students gathered the following information on the density of copper. The accepted value for the density of copper is 7.50g/cm³. Determine the mean, mode and average of the following data. What is the percent error? Identify the maximum and minimum values.

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.22</td>
</tr>
<tr>
<td>2</td>
<td>7.65</td>
</tr>
<tr>
<td>3</td>
<td>7.51</td>
</tr>
<tr>
<td>4</td>
<td>7.49</td>
</tr>
<tr>
<td>5</td>
<td>7.48</td>
</tr>
<tr>
<td>6</td>
<td>7.93</td>
</tr>
<tr>
<td>7</td>
<td>8.02</td>
</tr>
<tr>
<td>8</td>
<td>7.43</td>
</tr>
<tr>
<td>9</td>
<td>6.97</td>
</tr>
<tr>
<td>10</td>
<td>7.51</td>
</tr>
</tbody>
</table>

Maximum: 8.02
Minimum: 6.97
Average / Mean: 7.52
Mode: 7.51
Median: 7.49
Percent error: \[(7.50 - 7.52)/7.50 \times 100 = 0.27\%\]
Appendix Y

Student Artifacts

Sample Webquest

3. Because of fossil fuels combustion and land use
4. Fossil fuels pollution is sea level rise and health effects.
5. New ways to produce carbon dioxide in metal manufacturing and 
   construction, rubber and plastic, and food and beverages.
6. Some health risks are Cecil kills malaria, schistosomiasis, and health 
   problems like a mosquito-borne illness.
7. Within the stratosphere, a concentration of ozone molecules
   make up the ozone layer.
8. A single, pure ozone molecule is 23. Like other molecules, they are 
   reactive. In one form, it is a product of other atmospheric gases, it 
   caused a greenhouse effect.
9. National program to protect the ozone layer also requires CFC 
   HFCs, reducing, development of substitute chemicals, banning.
10. As one, potentially viable option to achieve reductions in 
    include emissions and atmospheric concentrations.
Sample Roundhouse Diagram
Sample Multiple Graph of Tree Growth and Climate Data
Sample Statistics Activity

Statistics of Tree Growth

1. Using your tree cookie, determine the age of your tree. One year includes a light ring and a dark ring. 22

2. Determine the width of each growth ring beginning at pith and moving to the outside edge. Measure this in centimeters as accurately as possible.

Students completed this on a separate page

3. Make a table of this data with the ring closest to the nith labeled as year 1.

Students completed this on a separate page

4. Determine the average yearly growth. Add each width and divide by the number of years. 3.4

5. What is the maximum year’s growth? (largest ring) 120 mm

6. What is the minimum year’s growth? (smallest ring) 10 mm

7. What is the most frequent growth size? (mode) 20 mm

8. What is the median ring size? (one in the middle) 30 mm

9. Using your average as the true value, determine the percent error of the maximum growth and the minimum growth. Use the formula (True – Observed)/True x 100

\[
\frac{3.4 - 12}{3.4} \times 100 = 70.9\%
\]

10. Using the precipitation and temperature data for the Louisiana Climate, determine if temperature or weather is most responsible for variations in ring growth for your sample. Justify your answer.

Temperature is more responsible because there wasn’t that much precipitation.
Sample Climate Change CD Reading Guide

1. What is weather?
   - Temperature
   - Sunshine
   - Precipitation
   - Wind direction and speed
   - Humidity
   - Physical changes in the troposphere
2. How do weather and climate differ?
   - Climate is weather recorded over long periods of time.
   - Weather happens.
3. What factors can affect climate change?
   - Carbon cycle
   - Plate-tectonic cycle
   - Hydrological cycle
   - Human influence
   - Temperature will rise because more people are putting greenhouse gases in the atmosphere.
5. Why have scientists concluded that there has been a climate change in recent history?
   - Temperatures increase by 10°F in past century.
   - Precipitation patterns have been altered.
   - Sea levels have risen.
   - El Niño is more frequent.
   - Causes more hurricanes.
7. List ways in which climate change has been documented.
   - Global temperature changes
   - Ice core samples
   - Radiometric dating
   - Historical records
   - Sea sediments
   - Tree rings
8. You are asked to evaluate climate change records for the last 6000 years. Which method would you choose? What are the advantages and limitations of this method? Choose at least 6 factors to consider such as cost, ease of use, availability, accuracy, and two more of your choice to explain why you chose this method of tree rings because most places has trees available.
9. Who is Charles Keeling? What did he do?
   - Studied carbon cycle.
10. What information is provided in the “Koshland Science Museum” graph. Identify the time scale used, the parameters measured, the units for each parameter. Describe the trend that shows up in the graph. How do the parameters relate to each other?
   - Temperature, CO₂ concentration, ice age, El Niño carbon dioxide concentration in ppm.
   - Temperature in Antarctica.
Appendix Z
Rubrics for Student Activities

Roundhouse diagram (5 each)
— Goals clearly stated
— Title clearly covers concepts
— Diagram includes key concepts
— Clear integration of concepts
— Clear sequence, if present?
— Spacing
— Accuracy of information
— Applicability of illustrations
— Aesthetic, neatness, grammar
— Total (45)

Diagrams of angiosperm/gymnosperms (5 each)
— Both diagrams present
— All components identified for angiosperm
— All components identified for angiosperm
— Correctly drawn angiosperm
— Correctly drawn gymnosperm
— Correct identification of distinction between the two tree types
— Total (30)
Graphing of tree growth and statistical calculations (5 each)

— Tree correctly aged
— Measurements accurate
— Graph is correctly identified
— Correctly calculated mode
— Correctly calculated mean
— Correctly calculated median
— Correct minimum year growth
— Correct maximum year growth
— Ability to calculate percent error
— Correct interpretation of tree growth with climate data
— **Total (50)**

Experiment completion (5 each)

— Clearly justified purpose of the experiment
— Clearly stated hypothesis
— Follows a sound experimental procedure
— Data supports student claims
— Replication apparent
— Extraneous variables accounted for
— Data is accurately presented
— Aesthetic and grammatically correct
— Presentation of experiment is clear and informative (x 3)
— **Total**

Climate Change Activities (Correctness of answers)

— / _20_ Activity 1 (Climate Change CD Reading Guide)
— / _10_ Activity 2 (Terrace Temperatures)
— / _9_ Activity 3 (Tree Ring Climates)
Appendix AA

Model Diagram of a Tree Cross Section
Slide 1

Climate Change over Time

Slide 2

Weather

- Physical changes that occur in the troposphere
  - Temperature
  - Precipitation
  - Humidity
  - Barometric pressure
  - Sunshine
  - Cloud cover
  - Wind direction and speed
- Concerned with a given location in a given time period
Climate

- Concerned with the troposphere (first layer of the atmosphere from sea level to 17 km up)
- Based on analyses of weather records over a long period (at least 30 years)
- Main factors considered
  - Temperature
  - Precipitation

Cycles affecting climate change

- Carbon cycle
- Hydrological cycle
- Plate tectonic cycle

The Ocean’s role in the climate

- The ocean serves as a sink (storage or source)
  - Heat
    - 71% of the Earth’s surface
    - Water has a higher capacity for holding heat than does land
  - Carbon
- Changes in glacial ice affect ocean levels
Factors that can change climate

- Human influence
- Natural climatic variations
  - changes in the sun’s energy
    - Solar flares
    - Variations in the Earth’s orbit
  - volcanic emissions
  - Natural greenhouse gases
  - Continental positions
  - Astronomical collisions

How has the climate changed in the last century?

- Increased temperatures by almost 1°F in the last century
  - Increased by about one percent in high altitudes
  - In the United States the change has been approximately 5-10 %
  - More precipitation occurs between September and November in the Northern Hemisphere
  - Tends to occur in a more severe form
    - Hurricanes and tornados are more frequent and intense
    - Thunderstorms are frequently stronger
  - Decreased in the tropical areas
- Sea level
  - Risen by 15 – 20 cm
    - 2.6 cm is the result of melting glaciers
    - 2.7 cm through expansion due to increased temperature
  - El Nino Southern Oscillation phenomena has become more persistent

http://yosemite.epa.gov/OAR/globalwarming.nsf/content/Climate.html
Evidence of climate change in recent history

- Greenhouse gases have increased since pre-industrial times
  - atmospheric buildup of carbon dioxide is mostly the result of human activities
- Greenhouse gases (mostly carbon dioxide and water vapor) cause heat to build up in the atmosphere
- The warming trend since the late 19th century is associated with increased greenhouse gases
  - water vapor and carbon dioxide are the predominant greenhouse gases
  - Most of carbon dioxide increase is due to human activity
  - Has resulted in a change in atmospheric composition
- Although there is a cooling effect of pollutant aerosols, the greenhouse gas effect masks this change.

http://yosemite.epa.gov/oar/globalwarming.nsf/content/climate.html

Climate has always changed

http://www.koshland-science-museum.org/exhibitcc/historical02.jsp
Long term climate changes

• Temperature in the Antarctic has changed by as much as 20 °F in the last 350,000 years
• There is evidence that there is a temperature peak every 100,000 years
• El Niño has caused weather to cycle in periods of two to five years for thousands of years
• Younger Dryas was an exceptional period of glacial temperature that lasted a thousand years and ended abruptly with an increase in global temperature of 15 °F within a decade

Why are we concerned with past climatic records?

• To determine if the present trends in climate change are comparable to past changes
• To determine what past factors affected global climate
• To assess how aggressive actions should be to maintain our current climate
• To make predictions on how fast and how soon climate changes will effect global environments

Effects of climate change

• Higher temperatures
• Changes in precipitation patterns
• More severe weather events
• Stronger hurricanes and tornados
• Changes in sea levels and alteration of coastlines
• Loss of land area
• Loss of species diversity
Coastal erosion, California.

• Changes in climate may cause a threat to coastal areas due to an increase in erosion.
• Photo by Gary Lewis 1996.

How climate change is recorded

• Ice core samples from glaciers or icebergs
• Lake or sea sediments
• Coral reef deposits
• Radiometric dating
• Tree ring chronologies
• Historical records

Ice core samples

• Air bubbles are trapped as snow turns to ice.
• These are direct samples of past atmospheric conditions,
• The ratio of oxygen isotope concentrations helps to infer past temperatures,
• Concentrations of wind-blown dust, sea salt, pollen, forest fire smoke, and volcanic ash reveal conditions upwind.
• Variations in the Sun’s intensity can be determined
• Composition of space dust can has been collected and analyzed from the ice core samples
• Thickness of ice layers indicates levels of precipitation
Air bubbles in an ice core

Air trapped in ice can allow scientists to get a ‘time capsule’ of past atmospheric chemistry. Photo by Michael Morrison, Copyright 2003, Mothsmoke.

Boulders moved by glaciers

• Glaciers can transport rock material many miles away from their source.
• When a glacier melts, these rocks are left and are different from the local rock.
• They provide good evidence of past glacial activity.
• Photo GSA collection

Radiometric dating in water and carbon

• Water
  – Water may contain different isotopes of oxygen and hydrogen
  – Lighter water evaporates quicker than heavy water
  – The relative proportion of light and heavy water trapped in ice core samples provides an idea of the atmospheric temperature at the time when the water was frozen
• Carbon-14 dating
  – Useful for only 40,000 years
  – Results from the reaction of sun rays with nitrogen
  – Atmospheric carbon14 remains constant but organic carbon-14 degrades
  – Relative proportion of the two isotopes of carbon allow scientists to age organic fossils or other remains
Radiometric dating in minerals

- Relative proportion of radioactive isotopes in minerals allows scientists to determine time of origin of the minerals
- Isotopes in minerals: Carbon-14, Uranium-238, Uranium-235, Potassium-40, Rubidium-87
- Assumptions:
  1. Minerals from parent atoms (original isotopes)
  2. Daughters atoms cannot escape nor can parent atoms be added
  3. No geological process can restart the process

Great Barrier Reef, Australia

- Coral reefs are affected by any changes in sea level.
- Photo by Geoscience Australia

Coral reef samples

- Corals provide yearly records of tropical climates for several centuries.
- The living tissue is found only on the uppermost layer and leaves annual growth bands.
- The relative thickness of the bands depends on ocean temperature and salinity.
- Water temperature affects growth:
  - Warmer water leads to rapid growth and wide, porous layers.
  - Cooler water causes smaller, denser layers.
  - Extremely warm water may cause the coral to die (coral bleaching) or very slow growth.
- Water temperature also affects a coral’s chemistry:
  - Analysis of coral chemistry can help verify past climatic temperatures
Sea sediments

- Shells of tiny marine animals called “forams” (foraminifera) may be preserved in sediment.
- Relative proportions of warm-loving and cold loving organisms in the sediment layer give clues to temperature of the time period.
- The chemistry of the shells gives inferences on past temperatures and water composition.
- Types of rock and sand helps scientists deduce amounts and location of ice coverage.

Lake and pond sediments

- Cores from lakes and ponds contain remains of leaves, seeds, wood, and pollen.
- Analysis of vegetation from sediment cores help describe climatic conditions during the time the plants lived.

Glendonite

- Glendonites form in sediments when the water temperature is near freezing.
- They are good indicators of past glacial times. These are from rocks in SE Australia.
- They originated in the Permian age.
- Photo by Gary Lewis 1996
Tree Rings

- Trees in temperate regions produce annual growth rings that are visibly apparent.
  - Tree rings are light during early spring growth and dark during times of stress
  - Annual tree ring sizes vary depending on growth conditions
  - Anomalies in climate and environment show up in tree rings
    - Volcanic eruptions
    - Periods of drought
    - Periods of extreme temperature variations
    - Periods of solar variations
  - Cross dating of tree chronologies provide data for climate conditions for many years
    - Matching growth patterns across time and region extend the chronological record of tree rings
    - Archaeological wooden materials, old building wood, ship wood and charcoal can be used to date past events

Tree rings

- Tree rings provide evidence on changes in growth patterns due to climatic variations
- Photo by Tom Trower, NASA Ames Research Center

Historical records

- More accurate than natural archives
- Available for only the last couple of centuries
- Upper air observatories have been in use since World War II and record temperature, wind and humidity
Charles David Keeling

- Medal of Science for his lifetime achievement in scientific research.
- Studied the carbon cycle and the increase of atmospheric CO2.
- Important in the study of global climate change.
- The first to model the accumulation of atmospheric carbon dioxide.
- The "Keeling curve" shows 45 years of atmospheric carbon dioxide levels in Mauna Loa, Hawaii.
- His data confirmed that the increased accumulation of carbon dioxide produced by burning fossil fuels and other industrial products.

Keeling Curve

References

- EPA Global warming site. http://yosemite.epa.gov/oar/globalwarming.nsf/content/climate.html
# Appendix CC

## Experiment Evaluations

<table>
<thead>
<tr>
<th>Group (5pt/criteria)</th>
<th>Soil chemistry</th>
<th>Polluted leaves</th>
<th>Sunlight</th>
<th>Hill</th>
<th>Competition</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purpose</td>
<td>3/4</td>
<td>4/5</td>
<td>4/4</td>
<td>3/2</td>
<td>4/5</td>
<td>5/4</td>
</tr>
<tr>
<td>Hypothesis</td>
<td>5/4</td>
<td>4/5</td>
<td>5/4</td>
<td>3/3</td>
<td>5/5</td>
<td>5/5</td>
</tr>
<tr>
<td>Procedure</td>
<td>4/3</td>
<td>3/3</td>
<td>4/3</td>
<td>3/3</td>
<td>3/2</td>
<td>3/4</td>
</tr>
<tr>
<td>Replication</td>
<td>3/2</td>
<td>4/3</td>
<td>3/3</td>
<td>2/2</td>
<td>2/2</td>
<td>3/2</td>
</tr>
<tr>
<td>Data presentation</td>
<td>3/3</td>
<td>4/3</td>
<td>3/4</td>
<td>3/3</td>
<td>3/3</td>
<td>4/4</td>
</tr>
<tr>
<td>Conclusion drawn</td>
<td>3/3</td>
<td>3/3</td>
<td>2/2</td>
<td>2/2</td>
<td>4/3</td>
<td>2/2</td>
</tr>
<tr>
<td>Presentation (x 2)</td>
<td>9/10</td>
<td>10/9</td>
<td>9/10</td>
<td>8/9</td>
<td>7/7</td>
<td>8/8</td>
</tr>
<tr>
<td>Total (50)</td>
<td>38/38</td>
<td>40/39</td>
<td>37/38</td>
<td>34/33</td>
<td>34/35</td>
<td>38/37</td>
</tr>
</tbody>
</table>

Note: Scores are recorded as Researcher Score/ Teacher Score.
Appendix DD

Comparison of Pre- and Posttest

<table>
<thead>
<tr>
<th>STUDENT</th>
<th>PRETEST</th>
<th>POSTTEST</th>
<th>DIFFERENCE</th>
<th>RANK</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>18</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>17</td>
<td>-3</td>
<td>-1</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>16</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>9</td>
<td>24</td>
<td>15</td>
<td>24</td>
</tr>
<tr>
<td>5</td>
<td>11</td>
<td>30</td>
<td>19</td>
<td>25</td>
</tr>
<tr>
<td>6</td>
<td>9</td>
<td>20</td>
<td>11</td>
<td>16</td>
</tr>
<tr>
<td>7</td>
<td>6</td>
<td>16</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>14</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>20</td>
<td>11</td>
<td>17</td>
</tr>
<tr>
<td>10</td>
<td>17</td>
<td>30</td>
<td>13</td>
<td>21</td>
</tr>
<tr>
<td>11</td>
<td>4</td>
<td>16</td>
<td>12</td>
<td>20</td>
</tr>
<tr>
<td>12</td>
<td>6</td>
<td>12</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>13</td>
<td>3</td>
<td>12</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>14</td>
<td>3</td>
<td>14</td>
<td>11</td>
<td>18</td>
</tr>
<tr>
<td>15</td>
<td>9</td>
<td>19</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>16</td>
<td>15</td>
<td>23</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>17</td>
<td>5</td>
<td>16</td>
<td>11</td>
<td>19</td>
</tr>
<tr>
<td>18</td>
<td>13</td>
<td>10</td>
<td>-3</td>
<td>-2</td>
</tr>
<tr>
<td>19</td>
<td>23</td>
<td>32</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>20</td>
<td>18</td>
<td>24</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>21</td>
<td>6</td>
<td>16</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>22</td>
<td>12</td>
<td>25</td>
<td>13</td>
<td>22</td>
</tr>
<tr>
<td>23</td>
<td>4</td>
<td>9</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>24</td>
<td>4</td>
<td>17</td>
<td>13</td>
<td>23</td>
</tr>
<tr>
<td>25</td>
<td>10</td>
<td>18</td>
<td>8</td>
<td>9</td>
</tr>
</tbody>
</table>

AVERAGE 9.52 18.72 9.2
## Appendix EE
### Profile of Intervention Activities

<table>
<thead>
<tr>
<th>Activity</th>
<th>National Standard</th>
<th>State benchmarks</th>
<th>Evaluation</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>KWL / pretest</td>
<td></td>
<td></td>
<td>Pretest scores</td>
<td>Determine prior knowledge</td>
</tr>
<tr>
<td>Webquest on climate change</td>
<td>Personal and community health</td>
<td>SE-H-A11</td>
<td>Roundhouse diagrams</td>
<td>Define climate change</td>
</tr>
<tr>
<td></td>
<td>Population growth</td>
<td></td>
<td></td>
<td>Sketch the greenhouse effect</td>
</tr>
<tr>
<td></td>
<td>Natural resources</td>
<td></td>
<td></td>
<td>Identify major gases contributing to the greenhouse effect</td>
</tr>
<tr>
<td></td>
<td>Environmental quality</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Natural and human-induced hazards</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Science and technology in local, national and global challenges</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cross-section comparison</td>
<td>Matter, energy and organization in living systems</td>
<td>LS-H-D1 LS-H-F1 LS-H-F3</td>
<td>Labeled student sketches</td>
<td>Anatomy gymnosperm vs angiosperm</td>
</tr>
<tr>
<td>comparison angiosperm/gymnosperm</td>
<td></td>
<td></td>
<td></td>
<td>Identify regions of the anatomy of a tree cross section</td>
</tr>
<tr>
<td></td>
<td>Behavior of organisms</td>
<td></td>
<td></td>
<td>Determine statistics of measurements</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Recognize the degree of precision of instruments used</td>
</tr>
<tr>
<td>(cont’d)</td>
<td></td>
<td></td>
<td></td>
<td>Relate climate to variation in tree growth</td>
</tr>
<tr>
<td>Climate change CD</td>
<td>Energy in the earth system</td>
<td>SI-H-A4 SE-H-A5 SE-H-A7 SE-H-A11</td>
<td>Completion of Climate Change activities</td>
<td>Distinguish climate and weather</td>
</tr>
<tr>
<td>-------------------</td>
<td>-----------------------------</td>
<td>----------------------------------</td>
<td>----------------------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td></td>
<td>Geochemical cycles</td>
<td></td>
<td></td>
<td>Recognize patterns that can change Earth’s climate</td>
</tr>
<tr>
<td></td>
<td>Origin and evolution of the earth system</td>
<td></td>
<td></td>
<td>Identify and use the natural artifacts that scientist use to verify climate variations in the past</td>
</tr>
<tr>
<td></td>
<td>Understandings about science and technology</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Science as a human endeavor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nature of scientific knowledge</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Historical perspectives</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student exit slips/ post test</td>
<td></td>
<td>Post test scores</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Vita

Cynthia Stager McCormick was born October 29, 1952, in Lindale, Georgia. She is married to Michael E. McCormick and they have three children. She started her education in the public school systems of Georgia and Tennessee and graduated from Pepperell High School in 1970. She received a Bachelor of Arts in biology from Berry College (1973), a Master of Science in animal science from Virginia Tech (1977) and an Education Specialist Certification from Louisiana State University (2006). She received a Doctor of Philosophy from the Department of Education Theory, Policy and Practice from Louisiana State University in 2007. She worked as a laboratory technician in a wire manufacturing plant and as a research associate in agronomy with the Georgia Experiment Systems before entering the education field. She has taught mathematics and science at Franklinton High School for almost twenty years. She received the Franklinton High School and Washington Parish Teacher of the Year in 2003.