Examining student conceptions of the nature of science from two project-based classrooms

David M. Moss
University of New Hampshire, Durham

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Examining student conceptions of the nature of science from two project-based classrooms

Abstract
The purpose of this research was to develop descriptive accounts of precollege students' conceptions of the nature of science from two project-based classrooms, and track those conceptions over the course of an academic year. A model of the nature of science was developed and served as the criterion by which students' beliefs were evaluated. The model distinguishes between two major categories of science, the nature of the scientific enterprise and the nature of scientific knowledge. Five students were selected from each class and interviewed individually for 30-45 minutes each, six times over the year. Data from semi-structured, formal interviewing consisted of audio-recorded interviews which were transcribed verbatim. All passages were coded using codes which corresponded to the premises of the model of the nature of science. Passages in the transcripts were interpreted to develop a summary of the students' conceptions over the year. Qualitative methodologies, especially formal interviewing in conjunction with participant observation, were effective for uncovering students' conceptions of the nature of science, adding to the knowledge base in this field. The research design of the current study was a significant factor in explaining the inconsistencies seen between findings from this study and the literature. The study finds that participants at both classroom sites held fully formed conceptions of the nature of science for approximately 40 percent of the premises across the model. For two-thirds of the elements which comprise the premises, participants held full understandings. Participants held more complete understandings of the nature of scientific knowledge than the nature of the scientific enterprise. Most participants had difficulty distinguishing between science and non-science and held poor understandings of the role of questions in science. Students' beliefs generally remained unchanged over the year. When their conceptions did evolve, project-based instruction was sometimes a factor. Conceptual change theory provides a framework by which these changes can be understood. These findings demonstrate that merely involving students in science-related projects will not always foster an improved understanding of the nature of science. Implications for science teaching include making the nature of science explicit throughout instruction.

Keywords
Education, Sciences, Education, Secondary

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EXAMINING STUDENT CONCEPTIONS OF THE NATURE OF SCIENCE FROM TWO PROJECT-BASED CLASSROOMS

BY

David M. Moss
B.A. Alfred University, 1987
M.S. University of New Hampshire, 1991

DISSERTATION

Submitted to the University of New Hampshire in Partial Fulfillment of the Requirements for the Degree of

Doctor of Philosophy in Education

May, 1998
This dissertation has been examined and approved.

Eleanor Abrams
Dissertation Co-Director, Eleanor D. Abrams
Assistant Professor of Education

Judith Robb Kull
Dissertation Co-Director, Judith Robb Kull
Associate Professor of Education

Michael D. Andrew, Professor of Education

David S. Bartlett, Associate Director
Institute for the Study of Earth, Oceans, and Space

Barrett N. Rock, Director
Complex Systems Research Center

December 16, 1997
Date
DEDICATION

To Korina, for her unwavering support and patience regarding this entire endeavor.

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ABSTRACT

EXAMINING STUDENT CONCEPTIONS OF THE NATURE OF SCIENCE
FROM TWO PROJECT-BASED CLASSROOMS

by

David M. Moss

University of New Hampshire, May, 1998

The purpose of this research was to develop descriptive accounts of precollege students' conceptions of the nature of science from two project-based classrooms, and track those conceptions over the course of an academic year. A model of the nature of science was developed and served as the criterion by which students' beliefs were evaluated. The model distinguishes between two major categories of science, the nature of the scientific enterprise and the nature of scientific knowledge. Five students were selected from each class and interviewed individually for 30-45 minutes each, six times over the year. Data from semi-structured, formal interviewing consisted of audio-recorded interviews which were transcribed verbatim. All passages were coded using codes which corresponded to the premises of the model of the nature of science. Passages in the transcripts were interpreted to develop a summary of the students' conceptions over the year. Qualitative methodologies, especially formal interviewing in conjunction with participant observation, were effective for uncovering students' conceptions of the nature of science, adding to the knowledge base in this field. The research design of the current study was a significant factor in explaining the
inconsistencies seen between findings from this study and the literature. This study finds that participants at both classroom sites held fully formed conceptions of the nature of science for approximately 40 percent of the premises across the model. For two-thirds of the elements which comprise the premises, participants held full understandings. Participants held more complete understandings of the nature of scientific knowledge than the nature of the scientific enterprise. Most participants had difficulty distinguishing between science and non-science and held poor understandings of the role of questions in science. Students' beliefs generally remained unchanged over the year. When their conceptions did evolve, project-based instruction was sometimes a factor. Conceptual change theory provides a framework by which these changes can be understood. These findings demonstrate that merely involving students in science-related projects will not always foster an improved understanding of the nature of science. Implications for science teaching include making the nature of science explicit throughout instruction.
INTRODUCTION

As we approach the 21st century, the United States' continued need to compete effectively in a global economy, coupled with adequate science preparation required for American citizens to make informed decisions about environmental and social issues, such as global climate change (Keeling, Chin, & Whorf, 1996), have contributed to the development of several national-level proposals for science education reform (Eisenhart, Finkel, and Marion, 1996). The American Association for the Advancement of Science (AAAS), and the National Research Council (NRC) of the National Academy of Sciences have sponsored two such science reform initiatives. Although the proposals vary somewhat between these national organizations, they both share the overarching goal of "scientific literacy" for all Americans. Scientific literacy refers to possessing and using scientific knowledge to make decisions which affect our lives (AAAS, 1989), which includes an understanding of the concepts, principles, theories, and processes of science along with an awareness of the complex relationships between science, technology, and society (Abd-El-Khalick, Bell, & Lederman, 1997). The achievement of scientific literacy for all American citizens is viewed by many science educators as the educational solution to any economical, social, and environmental challenges we may face into the next century.

A common goal of the AAAS (1989) initiative, titled Project 2061, and the NRC's (1996) National Science Education Standards is the recommendation that precollege students develop an understanding of the nature of science as a key element
to achieving scientific literacy. This outcome is also widely advocated by prominent science educators (Boujaoude, 1995; Bybee et al., 1991; Lederman, 1992). In a review of the science education literature, Lederman (1992) uncovered that the nature of science as an objective for schools can be traced back to the early part of this century when in 1907 the Central Association of Science and Mathematics Teachers argued for an increased emphasis to be placed on the scientific method and the process of science. Today, the nature of science is generally characterized by the notion that the world is understandable through scientific inquiry, yet also recognizes that scientific ideas are subject to change (NRC, 1996).

As scientific literacy is in part characterized by the nature of science, there are various elements which make up the nature of science itself. The writers of Project 2061 (AAAS, 1989) define the scientific enterprise as a component of the nature of science. The scientific enterprise, commonly known as the process of scientific inquiry, has both individual and social dimensions. Developing researchable questions, collecting and analyzing data, and ultimately communicating results are all components of the scientific enterprise and therefore critical aspects of the nature of science as well. The developers of Project 2061 write, "There is simply no fixed set of steps that scientists always follow, no one path that leads them unerringly to scientific knowledge" (p. 26). They characterize scientific inquiry, or the scientific enterprise, as a process that while demanding evidence, blends logic and imagination in an attempt to explain or predict our natural world.

The National Science Education Standards (NRC, 1996) also advocates that
students develop an understanding of the nature of science through participation in scientific inquiry. The NRC points out that inquiry is a multifaceted activity that will enable students to develop an understanding of scientific processes, as well as an understanding of how scientists themselves study our natural world. In discussing the history and nature of science, they write:

Beginning in grades K - 4, teachers should build on students' natural inclinations to ask questions and investigate their world. Groups of students can conduct investigations that begin with a question and progress toward communicating an answer to the question. (p. 141)

Once again, the notions of questioning, investigating that question, and communicating the results are defined as critical components of the scientific enterprise and therefore of the nature of science itself. Throughout several waves of science reform, especially those of the post-sputnik 1960's, emphasis on the scientific process has been stressed, often at the expense of teaching science content (Welch, 1979).

The relationship between content and process is more complex and interactive than many educators may have originally thought (Prawat, 1992). Today, the NRC (1996) supports the position that the process of scientific inquiry should not be separated from scientific content. That is, scientific ways of knowing should be couched within a scientific context. For example, students would not merely learn the process of formulating questions in science, but would learn to formulate questions about a specific area in science, and pursue those questions so they could, as the NRC explains, "develop the capacity to conduct complete inquiries" (p. 23).

Developing that capacity may entail learning the nature of scientific knowledge, another important element of the nature of science. The NRC and AAAS define
scientific knowledge as demanding evidence, yet often being tentative and incomplete. Meichtry (1993) concludes that both the nature of scientific knowledge and the nature of the scientific enterprise taken together better define the nature of science, especially with regard to scientific literacy.

The National Science Education Standards (NRC, 1996) do not advocate specific teaching strategies for fostering an understanding of the nature of science in students. They state that, "Learning science is something that students do, not something that is done to them" (p. 20). They strongly advocate an active hands- and minds-on approach. Project 2061 (AAAS, 1989) argues that students need time to explore, make observations, and make wrong turns throughout the process of learning science. But how can we ensure an active approach to science education that allows students' adequate time to conduct investigations so that they may develop an understanding of the nature of science? Perhaps a project-based approach to teaching science will help meet both national organizations' recommendations.

There is much written on when, how, and why projects should be used in schools (Morgan, 1983; Wolk, 1994), especially in science education (Ladewski, Krajcik, & Harvey, 1994; Scott, 1994). Katz (1994) defines a project as an in-depth investigation of a topic worth learning more about, and states that a key feature of a project is that it is a research effort deliberately focused on finding answers to a question. In a recent book developed to aid teachers in improving their science teaching, Glasgow (1996) notes that science projects should also be authentic, that is, mirror the way science is actually done in working laboratories and field sites. He
believes students should have the opportunity to create new knowledge by exploring original questions. By encouraging students to pursue projects in science, specifically ones in which they make observations, formulate questions, conduct research, analyze data, and report their results in a classroom or public setting, perhaps we can foster their exploration of the nature of science.

Examining the nature of science within project-based classrooms, specifically student understandings of the nature of scientific knowledge and the scientific enterprise, was the focus of this study. The guiding research question for this descriptive study was:

What conceptions of the nature of science do precollege students hold and develop over the course of an academic year?

This research question was developed, in part, throughout the course of conducting a pilot study over the 1995-96 academic year. A brief discussion of the goals, methods, and results from that pilot effort appear in the first chapter.
CHAPTER I

SETTING THE STAGE

Pilot Study

During the summer of 1995, a retreat was convened to discuss the future of science education research at the University of New Hampshire. At the time, I had just completed my first year of full time doctoral work and was eager to jump into a research agenda which I thought might help orient me toward a dissertation topic. I had experience conducting research, although it was in the area of forest ecology working with trees, not in the field of science education working with students and teachers. I sincerely hoped the teachers and students would be as cooperative as the trees had been.

At the time, I was not short on ideas, but on focus. The national standards were prominently discussed in the literature, and perhaps like many doctoral students in science education I figured there must be a dissertation topic somewhere in those documents. For several hours I batted around the notions of big ideas in science, misconceptions, and student attitudes toward science with UNH faculty and science teachers. Eventually, we discussed the various large scale projects underway, such as The GLOBE Program (GLOBE, 1996) and Forest Watch (Rock & Lauten, 1996), which were designed to incorporate various aspects of curriculum reform discussed in those standards. Finally, we landed on the notion of a "model curriculum." That is, a curriculum which embodied many of the ideas outlined in the various reform
documents. We wondered what such a curriculum might look like. We agreed it certainly could include such projects as GLOBE or Forest Watch. Perhaps it might even be entirely project-based. Throughout subsequent discussions many questions regarding these specific projects as well as project-based curriculum in general arose. The most significant questions for me included: What educational benefits did students really derive from participating in projects? What did they really learn about science?

Together we embarked on a year-long collaborative endeavor which would, in part, serve as the pilot study for this dissertation. Following that retreat, a research effort was initiated to determine to what extent year long project-based curricula had on student learning of the processes by which scientific knowledge is constructed. More specifically, we wished to examine the conceptual development (Driver & Scanlon, 1988; Linder, 1993; Posner, Strike, Hewson, & Gertzog, 1982; Southerland, 1997) of high school students' understanding of scientific research over an entire school year.

From the earliest stages of planning, I anticipated spending two full years in the field to collect data. This first year would allow me to gather experience in the methods of data collection, such as participant observation and student interviewing. In addition, I acquired experience in data analysis and writing. It also afforded me the opportunity to further clarify my research questions for subsequent investigation for the "full blown" dissertation during the second year of the study. We viewed the pilot study as essentially casting a broad research net. We purposefully examined student conceptions in a diverse set of areas such as models, systems, technology, and
scientific research. All the while I looked forward to conducting my own study during the second year of the research effort. When I eventually decided upon investigating student conceptions of the nature of science, I felt I had finally identified the focused topic that I had been searching for from that very first retreat.

The next two sections of this chapter will briefly discuss the goals, methods, and conclusions resulting from that pilot study. Findings from each of the two classroom settings will be discussed separately in each section, followed by a final section which outlines the research questions and justification for the second year of this dissertation research.

Valley High School

We first entered Valley High School (pseudonym), a semi-rural New England public school, in the fall of 1995 with the primary goal of uncovering and documenting any conceptual change regarding student understandings of the process of scientific research. Conceptual change theory (Driver & Scanlon, 1988; Linder, 1993; Posner et al., 1982) provided the theoretical framework by which we examined students' knowledge of scientific research. Posner and colleagues (1982) describe their conceptual change theory as explaining the methods by which individuals construct and modify their existing knowledge, such as when a learner captures new concepts or restructures existing concepts. This theory usually deals with key or central concepts, such as the understanding of scientific research, and states that conceptual change occurs when learners recognize shortcomings in their current understandings and
discover or are shown more plausible, intelligible alternatives.

The research methodology selected for this pilot study was qualitative in nature. Seven students from one combined 11th and 12th grade Conservation Biology class were selected after several weeks of participant observation, based on willingness to participate, gender, and achievement history. Four males and three females were selected after the observation period. Purposeful sampling was sought for maximum variation (Patton, 1987), therefore the students ranged in ability-level. Two students (one male and one female) were classified according to achievement history in science as high achievers, three students (two males and one female) as mid-level achievers, and two students (one male and one female) as low achievers. Data for this pilot research effort consisted of audio-recorded, semi-structured student interviews which were transcribed verbatim. Students were interviewed individually for approximately 30 minutes each, six times over the course of the school year. Students' conceptions regarding scientific research and big ideas or common themes in science, such as models and systems (AAAS, 1989), were tracked over time. The following core questions were utilized when interviewing participants at both Valley and Woodland over the course of the year:

What have you done so far in class? What have you learned?
What would you like to do in class? What would you like to learn?
Do you like this class compared to your other classes? What would you keep or change?
What project are you working on now? Is it research oriented?
How do researchers develop their questions? For example, scientists?

How do you determine if a research question is doable?

How do you know when your project is done?

What does a scientist do?

What is your definition of science?

Notes from frequent classroom observations and the use of classroom artifacts, such as completed projects, were used to triangulate findings.

A content analysis of the transcripts was performed and the results were reviewed and compared to a model of scientific research developed for the purpose of this pilot study. This simple 5 step model includes the major phases of the scientific enterprise: (1) the development of researchable questions, (2) data collection, (3) data analysis, (4) drawing of conclusions, and (5) communication of results. This model was derived from various sources including national science education standards (AAAS, 1989; NRC, 1996), discussions with scientists, and my own experiences conducting scientific research (Moss and Rock, 1991). For purposes of this study, this model was considered to be linear, with each distinct step leading to the next. However, it is recognized that for scientific research, latter steps often inform earlier ones, and there is commonly a blending of the activities which comprise this model. This early model served as the foundation for an expanded model of the nature of science which was developed following the completion of the pilot year and utilized in the analysis of data from the second year. A detailed discussion of qualitative methods, including this model, appears in Chapter III.
What follows is a summary of the results from the pilot study, including brief
descriptive accounts of student conceptions of scientific research. These conceptions
were developed by students while they participated in student-scientist partnerships
(SSPs). SSPs encourage students and scientists to collaborate on authentic scientific
research projects. A more detailed presentation of these pilot data can be seen in
Moss, Abrams, and Robb Kull (in press) in which a detailed discussion of SSPs can
be found, which includes recommendations for scientists, teachers, and science
educators.

The Setting

Students at Valley High were involved in a series of classroom projects during
the course of the school year. They participated in a local watershed monitoring
project which lasted the first half of the year, a computer-based population dynamics
modeling project which only lasted several weeks in duration, a land cover/land use
mapping project using Landsat Thematic Mapper (TM) satellite data which also lasted
several weeks, and a statewide environmental monitoring project of white pine (Pinus
strobus), titled Forest Watch, which comprised the bulk of the end of the year. The
watershed and white pine projects were guided by curricula that were developed in
part by scientists, and were designed to foster SSPs between the students at Valley
High and scientists engaged in active research programs in those areas. In addition,
these SSPs incorporated real world, authentic scientific research projects, as defined by
Glasgow (1996), into this classroom setting. That is, students pursued questions
through the collection of original scientific data. The watershed project monitored water quality along a major waterway in the state, and the Forest Watch project monitored tropospheric ozone damage to white pine trees.

The Conservation Biology course itself was designed from the beginning to provide a project-based, hands-on experience for students. It was designed to afford students the opportunity to experience "real" scientific research. Unlike many science activities at the high school level throughout the country, the science work in this project-based course had few canned or predetermined answers. These projects were designed such that they represented a significant step away from "cookbook" activities which merely verify already known scientific knowledge (Clough and Clark, 1994).

The Conservation Biology class was taught by Daria, a teacher with nine years of teaching experience. She has been teaching the Conservation Biology class at Valley High for 2 years. In 1995-96, she taught three sections of this class with each section having approximately 20 students. The class met for one 50 minute period each day. Since Valley High is a member of the Coalition of Essential Schools, students experienced what may be described as a progressive education (Backstrom, 1995). Students were often required to demonstrate their learning through the use of authentic assessment strategies, such as presentations, as opposed to traditional testing methods seen in many schools. In addition, no bells sounded throughout the day to mark the passage of each period while students were often seen in group discussions in the classrooms and hallways throughout the day. Cooperative learning experiences for students were fostered by many faculty members.
Meet the Students

**Matt** - Matt was a senior at Valley High during the course of our study. Much of our dialogue with Matt centered around the notions of questioning and data collection while data analysis and communication were rarely discussed. He had naïve conceptions regarding scientific questioning which did not evolve over the course of the school year believing that scientific questions can always be fully answered, and believing that every question one can pose is researchable.

With regard to data collection, Matt expressed at several points throughout the school year that data collection was repetitive. When discussing the data collection activities for the Forest Watch project Matt stated, "From what I've done so far it's kind of boring because it's all measurements, you have to do it over and over again." For Matt, his experience with an authentic research process was one that I would define as relatively uneventful. He plugged along throughout the class, but was never really excited by what he perceived as "doing real science."

**Julie** - In contrast, although Julie also felt data collection activities were repetitive and felt it consisted mostly of "filling out data sheets," she expressed a strong desire to do more data analysis as part of the projects. Julie was a junior, very athletically inclined, outspoken, and college bound as she was at the top of her class. She was quite critical of many aspects of this class, feeling that the pace of the class was determined by the class's ability to move forward as a unit. There were many times she was ready to move on through various phases of the projects, but since the class worked as a team she often felt held back.
She believed the analysis of data provided relevancy and meaning for doing the work. In discussing some of the little analysis she did following the extensive data collection activities for the watershed project, she said:

We're going to a different facet of it. Now we're...analyzing. We're applying to basic, like real life. Like right now that's what I'm happy about that we're applying to real life. It's interesting to me because I'm applying something. It's not just information on a sheet of paper. I'm going to apply it. I'll know now...I know how it'll affect the stream and if I have to make a decision like that. But before we did the water quality indexes, we just did the facts and it was just like busy work, kind of that went on for like three weeks and that was way too long. So right now I'm enjoying it. But before I wasn't at all.

With regard to scientific questioning she did not view questions as guiding the class projects. She felt the class was "told what to do" as opposed to investigating their own questions. She envied scientists, believing that scientists have limitless resources to pursue all questions as opposed to schools which have many limitations in this regard.

Bob - Another outspoken, often critical student in the class was Bob, although his comments were not necessarily directed toward the Conservation Biology class in particular, but schooling in general. Bob was a junior, and although he indicated a desire to attend college, his grades and general lack of motivation will likely make it difficult for him to succeed there. In analyzing the transcripts from Bob's interviews several important themes emerged. First, Bob felt that Daria (the teacher) was the guiding force for all of the projects. In discussing what guided the research, specifically the ideas and directions for what to do, he commented, "They came from Daria. She would say this is what you do...she would say interpret it... measure this, measure that."

Although he felt questions were a key element in science, he did not see
questions, but rather the teacher's direct instruction as guiding the class work. He expressed a desire to pursue his own questions and areas of interest in the class. At one point early on in the school year our dialogue turned to alternative sources of energy available for our region, and he expressed interest in pursuing questions in that area:

There's so many things I'd love to embark on. Like I'd love to go on a trip to a nuclear reactor. I'd love to just think and think and think and bring up all of these new topics (for study in class). That would be nice.

He wished to examine a broader range of issues than were covered in the Conservation Biology class. Like Julie, he stated that much of the year was spent on data collection activities, however he often had difficulty explaining what those activities measured or why he was doing them.

Marie - Marie was an above average, quiet, dedicated student who rarely spoke in class, but always did her work. Like Matt, much of our dialogue centered around questioning and data collection while data analysis and communication of results were rarely discussed. Like her peers thus far, she had no notion of the guiding scientific questions for the projects, but felt that Daria had an essential question which directed the work. Essential questions were commonly used throughout this school to set the stage for investigations or projects in many classes. However, they need not be researchable scientific questions, but more general areas of inquiry that direct the students' exploration of projects. In Marie's case she knew that Daria must have an essential question by which she was teaching the class (many teachers did), but could not remember what that was at any point throughout the year. Also, like her
classmates she felt Daria had chosen the essential question and considered that question provided for her and her class.

Like both Julie and Matt she felt the data collection procedures were repetitive, and ultimately she did not feel like a scientist. At the end of the year, we were discussing if she would have liked to go deeper into the projects with regard to data analysis. She responded:

No, I think we were pretty okay with all of that. We didn't go too much in depth, but just enough I think. We're not like scientists, so we don't want to go all they way in depth, so I think it was all okay.

Unlike Julie, she did not have a strong desire to do more data analysis; the little she did she felt was enough for her. She believed scientists should and probably would do more analyses.

Hank - Hank, a junior, struggled with school, barely passing classes. Often a disruption in other classes, he became engaged with the projects in this class. With regard to questioning, unlike most of his peers, he was able to articulate that specific questions guided the watershed project:

I think the (question) was probably just like how polluted is the water? How polluted is the environment? Like does it smell or is it safe? Can you get like skin rashes from the water or like if you drink the water will you die? Even like how many macro-invertebrates are there, things like that.

In addition to understanding and articulating the guiding research questions for the class projects, at the beginning of the year he had some of his own questions that he would have liked to pursue. However, it is important to note that Hank did not have the opportunity to pursue any of his own interests at any point throughout the year while participating in SSP activities in this class.
We did have the opportunity to discuss the communication of results with Hank as well. He expressed difficulty in communicating ideas to his peers in a classroom setting, "I wish that I could've presented better. I froze up...I couldn't do it because I had to deal with the whole cycle of nitrates and phosphates when it gets into the water." In addition to presentations, in which the entire class participated as a primary means for grading, he perceived field journals and the class log as forms of communication. Although he felt communication was important and could be an effective way to convey information, he personally had difficulty in conveying scientific ideas in a presentation format.

Celine - Celine was a junior who initially had very little interest in this class or in any topic remotely related to science in general, although that changed somewhat throughout the year. She is generally a below-average student. Like many of her peers she was unaware of a guiding question for the watershed project. She was quite sure that Daria had provided one and that it must be in the class syllabus if we were interested in seeing it. With regard to her understanding of a guiding question for the Forest Watch project, our discussion went as follows:

Researcher: What's the question that you're trying to answer out of this project?
Celine: I'm not quite aware. I'm sure I know there is one, I just probably don't recall it but it's probably along the lines of forest health. Anything along the lines of forest health I imagine would be it.

Although she was unsure and unable to articulate a research question, at least she did have the correct notion of the overall theme of forest health guiding the project. In addition, Celine had no real notion of what might happen with the data from the study:
Researcher: So what are they going to do with the (data) that you collect?
Celine: I don't know. I know they go to UNH.
Researcher: They go to UNH?
Celine: Yeah.
Researcher: So it's like part of a bigger project?
Celine: Somewhat, yeah.

She felt the scientists at UNH (SSP partner school) would do something with the data, but she and her peers would not. She had no clear notion of the partnership, nor any interest in following up on the data collection activities.

Andy - The final student who participated in this research was Andy, who was a junior at Valley High. Andy was an above average, hard working student who enjoyed many aspects of this project-based class. Like Celine, although he was unable to articulate a guiding question for the class projects, he was aware of the themes of river and forest health which were characteristic of them. Throughout the course of the year he did develop a basic understanding of how scientists pose researchable questions. Approximately mid-way through the year he stated:

First you have an idea of what you want to do, then you research some...then the more you research the more your question gets specific. So, the more information you know, the narrower you can make it. So it's easier to answer...it has to be based on stuff already known.

Additionally, when we asked Andy if every scientific question has an answer he responded by explaining the dynamic, interactive nature of developing and answering questions:

Every question that you answer always seems to lead to more questions. Like you can always ask why. You can always ask why does this work? Why does this work? And you can't always explain it...why did that happen? And it keeps going around and around and around.

His conceptions of scientific questioning were more sophisticated than many of his
peers who held naive beliefs centering around the notion of posing and answering single, isolated scientific questions. When asked if he had the opportunity to develop or explore any of his own questions or interests with regard to the Forest Watch project, he responded:

The stuff we're doing, it's like, I don't know. It's mostly measuring things and that's not stuff that provokes a lot of questions. It's like measure the tree height. Ok. Measure this...all right. It's not really question provoking material.

This passage confirms similar sentiments highlighted by most other students, that a great deal of effort was expended in the data collection aspects of the project with little time directed toward a broader notion of scientific research. As Andy indicated, such an allocation of class time and energy may not be conducive to fostering the exploration and inquiry into scientific topics that one may wish to see as a component of a model which promotes authentic scientific research.

Summary

One of the major themes that emerged was the role of data collection within this project-based class. The combination of the lack of input into the question guiding each project, along with only minimal energy placed into drawing conclusions at the very end, led to extensive data collection activities for the students without any real notion of why they were conducting them. In a sense, an authentic research activity, collecting data, was done without any context. For Julie, in particular, going beyond data collection was where the real connection to her world began. For others, going beyond data collection was characteristic of real research and science, but was rarely
done.

Questioning was another important theme which arose from this pilot study. Most students were not able to see beyond the data collection activities to gain an understanding of the specific goals of the projects which were represented by the guiding questions, although many of them were aware of certain themes underlying each project. One possible explanation for this lack of understanding is that the students were not personally invested in these questions because they did not have the opportunity to help formulate them. If questions can, in part, come from the students perhaps they may develop a broader picture of the overall goals of the research effort. In doing so, data collection and other activities might become more meaningful and relevant for the students. In addition to a lack of input into questions which guided the class projects, it is important to note that students did not have the opportunity to develop their own areas of inquiry either. Although several students expressed a desire to explore related areas of research, they did not have the opportunity to do so.

Although students in the pilot study did experience some data analysis, drawing of conclusions, and communication of results, they did not spend a great deal of time focused on these areas of scientific research. With regard to data analysis, neither Marie nor Celine had the desire to participate in more of it. Celine felt she most likely could not conduct the analyses because of the mathematics involved, and Marie did not feel like a scientist so she felt there was no need to analyze the data. In either case, their direct exposure and participation in a broader notion of the process of science was limited. However, they were not concerned because they felt that the
scientists would probably handle that portion of the project. In contrast, Julie, Bob, Hank, and Andy did indicate that at least some point in the year they wished to experience more of the scientific process than data collection, even though they felt they had limited opportunity to do so. Most students felt the drawing of conclusions was an extension of data analysis and felt they had limited opportunities to experience that as well, regardless of whether they wished to or not.

As noted earlier, Hank had difficulty in communicating scientific results to his classmates, yet class presentations were a large factor in student grading. Presentations were often reserved for the end of the projects, and students were graded based on a rubric which rated their understanding of various concepts and skills on a four point scale. Presentations were often done in groups, with each individual member being responsible for one aspect of the presentation. For example, one student might summarize the techniques used to collect certain data while another member might show the actual data collected. Rarely, if ever, were students responsible for demonstrating their analyses or conclusions drawn from the data. Considering the fact that students did not complete many analyses over the course of the year, it is not surprising that their presentations reflected a lack of them.

One final theme that emerged from the dialogues with the students involved their conceptions of the partnership with regard to the SSP model. One of the major points with regard to the partnership between UNH and Valley was the lack of direct contact between the partners from the students' perspectives:

Researcher: Have you had any contact with UNH?
Matt: Not directly.
Researcher: Not directly. Do you think it would have made a difference in (your enjoyment of) the program?
Matt: Probably not.
Researcher: Would you have liked to?
Matt: Doesn't really matter to me.

Several students did not even seem aware that scientists were involved with the project. They were unaware of the real scientific research in which they were participating.

As a result, students' conceptual understandings of the scientific enterprise rarely evolved over the course of the year, remaining rudimentary. Generally, they had naive notions of either guiding or researchable questions, viewed data collection as exactly following prescribed steps and ultimately repetitive, and had little experience with data analysis or the communication of scientific findings. Perhaps this is not surprising considering that conceptual change is believed to occur if learners recognize shortcomings in their current understandings and discover or are shown a more plausible, intelligible alternative to their beliefs (Posner et al., 1982). Since students did not directly experience a broad notion of scientific research, perhaps they did not have an alternative model by which their conceptions of that model could evolve.

The next section will briefly discuss the results from the second classroom site of the pilot study. The conclusion of this chapter contains a sub-section which outlines the research questions and justification for the second-year dissertation study.

**Woodland High School**

We also entered Woodland High School (pseudonym), a semi-rural New
England public school, in the fall of 1995 with the primary goal of uncovering and documenting any conceptual change of student understandings of the process of scientific research. The same conceptual change theoretical framework and qualitative methods utilized at Valley High School were employed at this field site as well. At this site, three students (one male and two females) were classified according to their achievement history in science as high achievers, two students (one male and one female) as mid-level achievers, and two students (both males) as low achievers.

The Setting

Woodland High School is a traditional high school. The narrow halls are lined with lockers, and at the sound of a bell, students move from class to class throughout the progression of their day. As one walks down the hallway during class time, it is not uncommon to see teachers lecturing to students who are sitting in neatly lined rows. Assessment was typically accomplished through multiple choice or open-ended testing, not through the use presentations or rubrics. In addition, most classes relied on texts, not projects to guide their curriculum. However, within Woodland the Project Seafarer class clearly broke from the school norm.

Project Seafarer is a project-based class where two teachers, six University of New Hampshire teaching interns, and 12 mentor teachers from various discipline areas facilitate student learning through the construction of an authentic 19th century whaleboat. In addition, students are encouraged to generate their own areas of inquiry, and pursue those areas through the completion of individual projects loosely based on
the whaleboat theme and tightly linked to their individual discipline. Unlike much of
the rest of the school, students were assessed using rubrics when presenting their
project work. Both content and process were evaluated.

The class is lead by Jack, a teacher with 19 years of experience. The Seafarer
class itself met five days a week on a rotating block schedule with either two or three
of those days each week being "double period" days in which the class met for two
back-to-back 45 minute periods instead of one. Eighteen students were enrolled in one
industrial arts credit for the first semester and a computer class credit for the second
semester along with one "academic" credit of their choice for each of the two
semesters. For this pilot study we attempted to select students who chose a science
related academic credit because their projects would then naturally be geared toward a
science area.

What follows is a summary of the results of the pilot study from this second
classroom site, including brief descriptive accounts of student conceptions of research.
A more detailed account of results from this year-long effort can be seen in Abrams,
Moss, and Robb Kull (in preparation).

Meet the Students

Catrina - Catrina was ranked one of the top students in her senior class, and
entered this project-based class with a bright and cheery attitude toward what she
considered to be a new way of learning. She specifically looked forward to building
the boat, anticipating that she would learn new woodworking skills which might serve
her later in life. She also liked the freedom which the individual projects gave her over what she was learning in the academic portion of the class. She stated early on in the year:

I like the freedom of the class, not the teacher lecturing you. It's up to you to learn and to get it done. Everybody's doing something different, and that's kind of interesting too. You look up and you don't see everybody doing the same thing.

Although her academic credits were history and creative writing first and second semester respectively, we often discussed the idea of research in science as well as in her selected areas of study within Seafarer. When discussing the nature of research in both science and non-science areas, she stated:

It's hard to explain. My (non-science) research is more research out of books. Taking...information kind of. Rewriting it to form my own opinions. Their (scientific) research is, there's nothing before them...they're not taking it out of books and reading it.

She recognized that her projects were fundamentally different from projects in which scientists may be involved. Her research entailed looking up information in a book, or from the internet later in the year, and that she did not collect or analyze her own original data. In addition, although she did not deal with science per se in this class, questions and communication played an important role in her projects even if they were not scientific questions or the communication of scientific findings. Questions guided what she "researched," and presenting her projects in small group settings served as the primary means by which she was evaluated over the course of the year. She steadily improved in both questioning and presenting throughout the year.

Samantha - Although also a senior, Samantha approached Project Seafarer a bit
more cautiously than did Catrina. She was ranked academically as an average student throughout her high school career, and perhaps not unlike many teenagers seemed more interested in budding romances than focusing on her school work. Early in the year she had great difficulty working independently on her project dealing with why cement boats are able to float (she pursued a credit in physics each of the two semesters). Regarding her difficulties working in this new class setting, she discussed her expectations for the class and her desire for more direction from the mentor teacher:

I think I was figuring more along the lines of like I'd have an independent study, but I'd have like you know my mentor teacher like tell me what to do it on and then I'd go off and do this project...but now it's more like I have to decide what I want to do and then it's kind of like I have to do everything. Like I have physics all year long for my thing and I don't really know anything about physics so it's like coming up with ideas is like, how do you do that?

She felt that generating a question, designing and completing a project, and presenting her work was difficult to do essentially on her own. Like Samantha, most students met very infrequently with their mentor teacher and rarely collaborated with their peers on academic work. Although interns were ever present in the classroom during academic period, and often described as overbearing by the students in the beginning of the year, the students still looked to their mentor teachers as ultimately defining what they needed to do and often felt isolated when pursuing their academic projects.

Interestingly, although she found this class format extremely challenging she saw it as potentially better than traditional classes because it could lead to improved learning. She described what she learned in Seafarer as "understanding" as compared to her peers in a traditional physics class whom she perceived as although covering
more material, actually learning the material less:

I'll understand the things I'm doing whereas they're probably going through the books and like getting a basic understanding of everything and just keep on going like they're marching on and I'm just like focusing on one thing at a time so I'm not going to get through as much...

However, she did in a way envy those students who learned from a book because she did desire more direction from her interns and mentor teacher, "In a way I kind of wish I could just like take the book and do like all book work...". She described herself as one who did well in that traditional setting. To her, that setting was a familiar one in which she knew the "rules" of how to get a good grade.

Unfortunately, in Samantha's case learning "less" was not necessarily "more". At the conclusion of the cement boat project, as well as with a project that dealt with vectors, she demonstrated only partial understanding of the physics concepts underlying each project. Although she improved in the generation of questions and the actual presenting of information (the process skills) over the year, she had difficulty in learning scientific content. She did, however, collect and analyze original data on occasion for her projects, such as information relating to why certain boats can float, so she was at least introduced to those aspects of scientific research even if that exposure was quite limited.

Ian - Although Ian chose an environmental science credit for the first semester, he did not have the opportunity to collect or analyze any original data throughout the completion of his science oriented projects. His first project, which dealt with why there were fewer fish to be caught by commercial fishermen off the coast of Maine, was similar in nature to most of the projects completed by students in Seafarer. For
Ian, and most students, research was collecting information from books in the school library, off the internet, or contacting experts in a given subject area. Data collection was therefore gathering that information, and analysis of that data was merely sorting through it to provide an "answer" to the question which guided the project.

Ian, a senior, was an average student unmotivated in academic areas, but very interested in the actual building of the boat. He often remarked that he wished there was more "boat time" and less "academic time." Like Samantha, he desired more direction from his mentor teacher. Early in the year he stated:

(I want) him involved a little more in the class. It's more like the kids are teaching themselves what to do, which is what it's supposed to be I know, but give a little guidelines.

During interviews, he had no difficulty articulating questions which guided his science oriented projects. They were, "Why are the fishing banks closing?" and "Why do ducks migrate?" However, for the second semester in which he pursued a reading credit, which he needed to meet the requirements for graduation, he found it difficult to formulate a question regarding poetry that he read. Regardless, all questions throughout the year were stated in such a way that it was not necessary for him to collect original data in search of an answer. The questions were more guiding questions as opposed to researchable questions in which he could have designed an experiment or tested a hypothesis. Midway through the year he defined research as, "Finding information either through people or through books, and writing down important points."

Ian often described himself as having a strong interest in science, however he
felt the whaling theme surrounding the class limited his exploration of his true scientific interest: space science. He defined science as solving problems, but his questions, lack of organizational and time management skills, and poor motivation for academic work prevented him from experiencing problem solving in science. What little science work he accomplished was essentially reading about fish and ducks.

Drew - Similar to Ian, Drew was an unmotivated senior who, if given the opportunity to procrastinate, would. Unfortunately, he was a troubled teenager who was heavily involved with drugs. He readily admitted that he suffered from a lack of motivation and poor organizational skills. Throughout the year he made comments including, "I do need more discipline," when trying to provide explanations for why he wasn't getting any work done in class. His very first project, for a credit in math, was a self described "flop":

It wasn't just a flop by information. It was a flop by my own disorganization. I should have started on the computer presentation early...it was a flop. It wasn't even close to being finished. I was actually supposed to present it today, but that's not going to happen for a little while either.

He found it difficult to explore his first essential question "What is a sextant?" within a mathematical context. He uncovered a great deal of information regarding the history of who used sextants, but did not discover much information on the underlying mathematical principles supporting the use of them. He got quickly frustrated and subsequently floundered instead of either modifying the question in some way or moving on to the next project.

When he did eventually move on to his second project, it was his academic highlight of the entire year. His project dealt with modeling the size of a blue whale
using cones and cylinders to represent the shape of the whale. His question, "What is the volume of a whale?" he felt was a clear and concise question in which he could pursue and answer, and he did. During his presentation in which he described volume, scale, and other mathematical concepts he also discussed making use of even smaller cones and cylinders, along with other shapes, to more accurately represent an average sized whale.

Following this project, the year fell apart for Drew. He essentially did not complete another project for the year and withdrew from this project-based course which caused him not to graduate from Woodland. Throughout our interviews he often discussed how Seafarer would work for him because "I can just have my own little independent thing going on," even though he recognized it would take a considerable amount of effort. In the end, he was not willing to put in that effort. Approximately mid-way through the year he began to change his mind about Project Seafarer, "I thought what better way to do it (take a math credit) than through Seafarer? A better way would have been to just normally take it." At various times he wanted both more and less structure to this class. He knew it was not working for him but could not figure out why. Unfortunately, his lack of organizational skills, time management skills, and motivation were never overcome. Although he did have thoughtful notions regarding science and research, and understanding the concept of original research, he did not apply himself to this class and therefore missed the opportunity to further explore his ideas.

Meg - Although a highly motivated student, ranked third in her senior class,
Meg also dropped from Project Seafarer, but for much different reasons than Drew. Meg was often a vocal critic of this class, criticizing what she perceived to be a lack of focus and direction for the course. She often felt isolated when working on her academic projects, and did not enjoy the boat building aspect of the course very much. Regarding Seafarer, she stated at the beginning of the year, "It's more interactive. You learn a lot more. You get a lot more out of it. You actually learn where the resources are..." For Meg, research was a time consuming process which involved visiting regional museums, contacting people by phone, and locating original sources of information regarding her area of study. For first semester, her academic credit was in college composition, an advanced writing course, and she chose to explore "Women in Whaling." She had difficulty narrowing down what it was exactly that she was going to write about regarding this topic because she had vague researchable questions. Meg had not completed a single piece of written work by the end of the first quarter. This continued for the second quarter, but she finally turned in one 10 page paper by the end of the semester. Because of the broad nature of the topic she stated that it was impossible to research her area thoroughly. She often described resources leading to more resources, but was never quite sure when she had enough. That is, she never knew when her research was "done".

Ironically, she felt that there was ultimately too much teacher control in Seafarer, but it was a lack of direction in helping to narrow the scope of the project which led to her difficulties. For the second semester she pursued an art credit, but described that as "just painting." With only two weeks left in school she petitioned the
school administration to let her drop this class, and a deal was struck. She would drop
the industrial arts credit (she had hurt her leg and did very little in that area anyway),
but keep the art class as a non-Seafarer Independent Study. Although she recognized
this project-based class as a potentially exciting, interesting, and effective place to
learn, she was concerned about her class rank, and chose to drop it to preserve her
standing.

Danny - Another highly motivated senior was Danny, although his experiences
with Seafarer were far less dramatic than Meg's ordeal. He was a quiet student who
worked hard, kept to himself, and stayed focused on his goals throughout the entire
year. His long term goals included becoming a Wildlife Biologist, and he knew that
meant many years of college to which he first had to gain acceptance. He often
"worried" about many things regarding this class, and school in general, but this
misplaced concern did keep him on track.

Similar to Meg, his initial project was too broad. First semester, his academic
credit was in environmental science, and his area of inquiry centered around the
intertidal zone. Eventually his questions focused on the tides and marine life that dwell
in these coastal zones, but initially he admitted "I've done broad research on
everything, but now I need to get more specific." His first essential question of "What
happens in the intertidal zone?" caused him to spend a lot of time researching diverse
areas regarding this topic. Like most students, this research entailed gathering
information from books. At no time did he actually visit this ecological feature,
although he recognized one existed a relatively short driving distance from his
Because of the broad nature of this topic, he found it easy to gather information in this area, but also found it difficult to sort through the mounds of information he gathered:

Researcher: Do you find that it's a problem to get information?
Danny: No. It's trying to find out what the important information is...that's probably the toughest point. I have so much information that it's not hard to get what I need. It's just the opposite of not finding enough.

In discussing the differences between traditional classes at Woodland and Project Seafarer, he stated:

I guess in classes like that (traditional classes) it's more you're given the question and you have to answer it. In Seafarer, you come up with the question and you have to answer it.

Although he had difficulty developing his own questions throughout the year, he often stated that he felt like a researcher and enjoyed working on his own projects. For second semester, he pursued a reading credit and described the questions in this area as "fillers" because he felt reading was more "opinion" than the science that he had done first semester.

John - The final student at Woodland was John, a senior who had often achieved poor grades, but who usually made a sincere effort to do well in school. At the outset of the year, he admitted that he had difficulty with time management and organizational skills so he agreed to put himself on a rigorous weekly schedule. He accomplished this by presenting his goals to his mentor teacher at the beginning of the week, and reviewing his accomplishments at the end. In this way he felt "directed" by
the teacher and was better able to focus on the work at hand.

Like Drew, John also ran into a bit of difficulty on his first project, but he was able to bounce back and had a productive and challenging year. When discussing research, he described it as difficult at first, but once you got into it you were able to uncover more and more resources. He contrasted this with research for reports that he had done for traditional classes at Woodland:

I do (research) for other classes, but it's really not that hard because like if I did a report on a guy in economics...so they had all the economics books on the reserve shelves and everything, so it's a lot easier...(for Seafarer) you have to go start and find all the information yourself. Because of this independent work, he liked this class and like many students thought that he learned more in this type of project-based setting:

You learn better than reading out of a book and just reading and taking a test. You actually do it and it's part of, you put part of yourself in the project...and you just learn better that way.

He took his academic credits in reading and Environmental Science, although chose to do all of his projects on a science related topic. For his first project he chose to write on what Greenpeace was doing to protect endangered whales. He learned a hard research lesson when he called the regional offices of Greenpeace and told them that he was building a whaleboat: he received little cooperation from that potential source of information.

Mid-way through the year he stated, "You can't get answers if you don't ask questions." He believed questions developed from earlier questions, and he improved in the generation of researchable questions as the year progressed. In fact, his time management and organizational skills along with his presentation skills all developed
over the course of the year. For John, Seafarer was an all around success.

Summary

Wolk (1994), a proponent of project-based curriculum, states, "When children are free to choose their own projects, integrating knowledge as the need arises, motivation—and success—follow naturally" (p. 42). Although this was not always the case for students enrolled in Project Seafarer, this project-based class did help foster very positive learning experiences for many students.

Project Seafarer encouraged students to pursue individual projects, linked to the whaleboat theme, for their academic credits. For the most part, students had difficulty clarifying the scope and direction of these projects. Students were excellent in developing general themes, or guiding questions, by which their projects were based, but found it difficult to narrow those questions down to focus their research. A great portion of the students' time was spent struggling with the formation of these researchable questions, regardless of the academic area in which these projects were grounded. They were instructed not to develop "yes or no" questions, but many could not seem to find that middle ground in which they could identify a narrow, researchable area to explore. As a result, the questions were often too broad and subsequently led to difficulties during the research process.

Research for most of the students involved looking up information in books, visiting the World Wide Web (WWW) sites on the internet, or speaking with individuals via the telephone. Students either found resources scarce so they had
essentially no useful information, or so plentiful that they had difficulty deciding which information to use. Many students recognized their type of research as merely one type of research. Although they frequently recognized that scientific research was original research, and different from their own research, they did not frame their questions in such a way that it led to this type of original data collection. In one case, in which John wished to explore the effect, if any, of whale watching on whales, he stated:

Like you get in one area and you get whales with whale watching ships all around them and everything, and another one you leave them alone, they go about doing their own things. See which one survives longer...this group of whales or that group of whales. Then you got to do it more than once and make sure it is consistent.

In this passage he was describing an experiment that he felt could test his question first hand. He knew this type of project was not possible, so instead he researched what people involved with whale watching believed to be the answer to his question. Students were expected to complete a minimum of twelve major projects over the course of the year. Perhaps with fewer projects students could experience more original data collection and analysis. The data analysis that students experienced was mostly sorting of information that they acquired. There was little generation of new knowledge. However, in order for students to experience these aspects of the scientific enterprise first hand in this project-based format, they must first learn to develop researchable, doable questions.

Their questions led them to merely gather information for data collection, and as a result communication was mostly reporting on the information they uncovered.
However, students did have many opportunities to formally share their work. Grading was almost entirely based on student presentations. There was little time for informal communication between students. Although students worked in a team atmosphere and shared ideas during the construction of the boat, that portion of the curriculum was not emphasized as greatly as the individual academic projects during the course of the pilot year.

Many students felt that they could learn "better" in Seafarer than in their traditional classes. They cited freedom to explore ideas along with a minimum of teacher directed "meaningless busy work" as being the most significant improvements over other classes. However, one final roadblock for many students which may have prevented them from deriving a more positive experience from this project-based class was their lack of organizational and time management skills. The time to learn these necessary meta-cognitive skills is not built into most national and state curriculums (AAAS, 1989; NRC, 1996). In Seafarer, it was hoped that students would develop these skills throughout the course of the year, but unless the lack of these skills was specifically addressed by the student and mentor teacher, students often had difficulties developing strategies to overcome their inexperience with these important skills.

On to the Second Year

Conducting the pilot study significantly shaped the scope and direction of what I came to think of as the "full blown dissertation." Throughout the course of completing the pilot study, I had the opportunity to explore the nature of the scientific
enterprise, which I came to think of as partially characterized by five phases of the scientific method: questioning, data collection, data analysis, drawing of conclusions, and communication of results. However, ongoing discussions with students piqued my interest regarding their broader conceptions of science in general, including their understandings of the nature of scientific knowledge. I had the opportunity to speak with them about their definitions of science in the pilot study, and I found their varied conceptions fascinating. Many students felt science was *everything* and could not be distinguished from other areas of inquiry. Others had difficulty expressing *any* definition of science at all.

Results from the pilot work suggested that the project-based classes at each school emphasized varying aspects of what I later came to know as the essence or nature of science. The Project Seafarer class at Woodland focused on questioning and communication, while the Conservation Biology class at Valley focused on data collection with minimal data analysis, although I believe both classes introduced their students to all aspects of the scientific enterprise at some level. There were many positive things happening at both of these sites, such as students being actively engaged in their work, and I very much desired to continue to visit both schools. The second year of this study allowed me to specifically examine student conceptions of the nature of science while at the same time continuing my work to explore the role that project-based curricula may have on those understandings.
Statement and Significance of the Research

This research is a descriptive study and builds directly upon findings of the pilot study. The overall purpose of this research is to create a descriptive account of precollege students' conceptions of the nature of science, and track those conceptions over the course of an academic year. Such descriptive accounts contribute to a growing body of knowledge within the science education community regarding student conceptions of the nature of science.

A model of the nature of science was developed for this study, in part, to serve as a lens by which student conceptions of the nature of science could be examined. In this sense, the model focused this study by defining the nature of science and providing criteria by which student conceptions were evaluated. Taken together, the various elements of each premise provide the reader with a model of fully formed precollege student conceptions of the nature of science.

In order to characterize the nature of science, the model distinguishes between two major categories, the nature of the scientific enterprise and the nature of scientific knowledge, and is presented in detail in Chapter II. Ideas distilled from the pilot study, science education literature, national science education standards, discussions with scientists, and personal experiences engaging in the scientific enterprise have contributed to this model. The premises which define the nature of the scientific enterprise include:

1.) The universe is open to human description, classification, and understanding through scientific exploration.
2.) This scientific exploration attempts to explain and predict phenomena, compare theories, check on previous results, and generate new questions.

3.) Logic, imagination, curiosity, and serendipity contribute to scientific exploration.

4.) Scientific activity is a social activity conducted by individuals who are influenced by both cultural and personal factors.

5.) Questioning, data collection and analysis, drawing of conclusions, and communication are the major phases which characterize the scientific endeavor.

The premises which define the nature of scientific knowledge include:

1.) Scientific knowledge demands evidence, and is testable through the scientific enterprise.

2.) Scientific knowledge cannot provide complete answers to all questions.

3.) Scientific knowledge is tentative, developmental, and subject to revision.

The guiding research question for this study was: What conceptions of the nature of science do precollege students hold and develop over the course of an academic year? Specific sub-questions include: (1) What are students' conceptual understandings of the nature of the scientific enterprise? (2) What are students' conceptual understandings of the nature of scientific knowledge? and (3) How may project-based teaching models affect students' conceptual development of these areas?
This research is significant for several reasons. First, it is widely recognized that the manner in which we teach science is in need of reform. The principal goal of this current reform effort is scientific literacy for all students (AAAS, 1989; NRC, 1996), not just teaching to our future scientists. National organizations such as AAAS claim that students must develop an understanding of the nature of science as an essential component of scientific literacy. This study will provide data regarding student understandings of the nature of science and track those understandings over the course of an entire school year.

Second, AAAS (1989) recommends that the teaching of science should be consistent with the nature of scientific inquiry. Therefore, throughout the course of the year science teachers should encourage their students to investigate and explore their world around them in a manner consistent with the nature of the scientific enterprise. Project-based teaching seems to support this notion of student inquiry, however, the role that project-based curricula may play in fostering an understanding of the nature of science is still unclear. Meichtry (1993) concludes that the question, "What are the instructional practices that facilitate students' understanding of the nature of science?" (p. 441) is an important science education research question to be examined through future research activities. Although the main goal of this research is to describe student conceptions of the nature of science, it will also address how instructional practices associated with project-based teaching models affect students' conceptual development in this area.

Studying conceptual change in students over long periods, such as a school
year, is also a very important area of needed research (Good, in press). Some long-term work has been completed in the area of genetics and evolution (Lawson & Thompson, 1988; Demastes-Southerland, 1993) and other science areas (Hashweh, 1988), but more work needs to be done to explain student understandings of the nature of science.

Finally, when discussing the future direction of science education research, Griffiths and Barry (1993) write, "While substantial attention has been paid to students' misconceptions and alternative conceptions of scientific concepts, parallel studies relating to the nature of science itself have been lacking" (p. 35). This study will help meet this gap in current science education research as well.
CHAPTER II

REVIEW OF THE LITERATURE

The Nature of Science

Defining the Nature of Science

Science curricula vary greatly among schools from different districts, states, and countries. Although no consensus exists regarding the specific content to be included in present day science courses or even the methods of instruction to be used, there appears to be at least strong agreement on one aspect of science instruction. The development of an understanding of the nature of science by precollege students is widely advocated as an outcome of science instruction (AAAS, 1989; Lederman, 1992; Lederman, Bell, & Wade, 1997; NRC, 1996; National Science Teachers Association [NSTA], 1982). A principal reason for this is that an understanding of the nature of science has been identified by scientists, science educators, and education policymakers as a key element toward achieving the overarching goal of scientific literacy (Meichtry, 1993).

The nature of science is defined broadly by the developers of Project 2061 (AAAS, 1989, 1993). It is characterized by three principal components: 1.) the scientific world view (the world is understandable, scientific ideas are subject to change, scientific knowledge is durable, and science cannot provide complete answers to all questions); 2.) scientific methods of inquiry (science demands evidence, science explains and predicts, science is a blend of logic and imagination, and scientists try to
identify and avoid bias); and 3.) the nature of the scientific enterprise (science is a complex social activity organized into disciplines). These various components deal with both the nature of scientific knowledge and the nature of the scientific enterprise. They illustrate that humans can come to understand various phenomena of the world in which we live through systematic study, and also emphasize the tentative nature of scientific knowledge. In describing the nature of the science, the authors of AAAS (1989) write:

The means used to develop these ideas (about our natural world) are particular ways of observing, thinking, experimenting, and validating. These ways represent a fundamental aspect of the nature of science and reflect how science tends to differ from other modes of knowing. (p. 25)

Moore (1985) further describes science as a way of knowing:

It is important to emphasize that science as a way of knowing is but one way of knowing. What we know in science must be based, in the final analysis, on data derived from observation and/or experiment relative to some natural phenomena. Those data must be...verifiable. (p. 487)

That is, a scientific way of knowing relies heavily upon empirical observation. By characterizing the nature of science, one can begin to differentiate between scientific ways of knowing and other modes of knowing, such as spiritual or philosophical ways of knowing.

In earlier work, Kimball (1968) developed a theoretical model of the nature of science based in part on the notion that curiosity is the fundamental driving force of science. Kimball also based this model on the belief that a basic characteristic of the nature of science is a faith in the susceptibility of the physical universe to human ordering and understanding. Kimball also noted that tentativeness and uncertainty are
indicative of all sciences. Similarly, Cothram and Smith (1981) use the terms tentative
and revisionary to define the nature of science. They point out that people who
understand the tentative nature of science as opposed to thinking of science as a
collection of immutable facts are less likely to be cynical regarding knowledge claims
made by the scientific community.

In an attempt to define and characterize the nature of science, these models
discuss both the notions of the scientific enterprise and scientific knowledge, however
Meichtry (1993) points out that the nature of science itself and the nature of scientific
knowledge warrant distinction. She notes that these two important dimensions are
often used interchangeably. She concludes that the nature of science is a broader
concept than that of scientific knowledge. This broader notion of the nature of science
includes scientific knowledge along with the nature of the scientific enterprise and the
nature of scientists themselves. Additionally, Good (1996) makes the distinction
between scientific knowledge and scientific thinking. Both distinctions, I believe,
distinguish scientific content from scientific processes. That is, scientific knowledge is
generated by the process of doing science.

Parker and Rubin (1966) provide excellent definitions of both scientific process
and content. Content is defined as "learning material...may consist of a related body of
facts, laws, theories, and generalizations, as in a traditional science course" (p. 1).
Rubba and Anderson (1978) developed a model of the nature of scientific knowledge
in which scientific knowledge is defined as amoral, creative, developmental,
parsimonious, testable, and unified. Showalter (1974) used the terms tentative, public,
replicable, and empirical to describe the nature of scientific knowledge. Parker and Rubin conclude that content is often transferred to the student.

Process, on the other hand, Parker and Rubin (1966) defined as:

All of the random, or ordered, operations that can be associated with human activities. There are a variety of processes through which knowledge is created. There are also processes for utilizing knowledge and for communicating it. Processes are involved in arriving at decisions...The scientist engages in what is perhaps the crucial process of his (or her) labor when he (or she) fabricates questions for which answers must be found. (p. 2)

When process is stressed, Parker and Rubin state that knowledge becomes the vehicle rather than the destination. They also note that knowledge keeps no better than freshly caught fish, which is even more true today than it was three decades ago. Linn and Muilenburg (1996) point out with the rapid growth of scientific information, tougher and tougher curricular choices regarding what knowledge to teach will have to be made.

More recently, science educators have explored the nature of science within an epistemological framework. Many researchers argue that students' conceptions of the nature of science should ideally be both broad and inclusive (Murfin, 1994). Stanley and Brickhouse (1994) argue against a universalist perspective of the nature of science, and argue for a multicultural perspective on the nature of science. In doing so, they question "Whose nature of science are we teaching?" Their question is both valid and important. They state that a universalist view of science claims that the scientific account of the world is unrelated to such things as human interest, culture, gender, race, class, ethnicity, or sexual orientation. This is clearly not the case. Such a view, they write, "ignores the role of the scientific community" (p. 390). In a response to
Stanley and Brickhouse (S & B), Loving (1995) argues that in teaching a culturally sensitive approach to science they are in danger of teaching multiple sciences in which they advocate relativism. S & B (1995) respond that "science is a cultural phenomenon and not a universal form of knowledge that transcends all cultural interpretations" (p. 353). In addition, S & B argue that just because there is no universal knowledge does not mean that one can not have a rational basis for making knowledge claims. Relativism implies that "anything goes" and that is clearly not the case. They state that in a sense we can only know what we know within a framework or frameworks, therefore no one has access to universal claims of knowledge and in that way our scientific knowledge is relative.

Martin and Brouwer (1993) explore other aspects of the nature of science or what they term "personal science." Through narratives they explore the personal science of Brouwer, an astronomer and science educator, and uncover what they define as significant aspects of science including, questioning, trust, perception, judgment, and doubt. Although questioning is often associated with science, rarely do we hear scientists discuss doubt or perception. Several of these notions are concepts that are probably not discussed within the context of most science classes. The process of science can often be personal and subjective. Knowledge is tentative and the researchers' own biases and experiences, along with their strengths and weaknesses, factor into data collection and interpretation. Words such as subjective and chaotic are most likely not common in science classrooms. Words such as objective and organized are, yet the former pair may characterize "doing real science" while the latter describes
learning about doing real science."

Each person undoubtedly constructs his or her own understanding of the nature of science based on his or her own experiences with it, which is why the experiences that students receive in the sciences are so critical. In order to examine student understandings of the nature of science with regard to the experiences they receive in the sciences, an fully formed definition or model of the nature of science should first be identified (Lederman, 1986). Lederman writes, "A precise definition of what constitutes an 'adequate' conception of the nature of science for teachers (or students) [sic] is conspicuous in its absence from previous research reports" (p. 92). Such a model, which defines a fully formed conception of the nature of science for use in this study is proposed in a later section.

Research on the Nature of Science and Scientific Knowledge

In a review of the literature, Lederman (1992) describes research related to the nature of science as falling within four related, but distinct, lines of research: (1) assessment of student conceptions of the nature of science; (2) development and assessment of curricula designed to improve an understanding of the nature of science for students; (3) assessment and improvement of teachers' conceptions of the nature of science; and (4) investigations into the relationship between teachers' conceptions, classroom practice, and students' conceptions of the nature of science. This research effort addresses the first line of research, the assessment of student conceptions of the nature of science.
In exploring the nature of science the first question that may be asked is, "What is Science?" Ryan and Aikenhead (1992) report on results from data gathered from a multiple choice instrument titled Views on Science-Technology-Society (VOSTS) in which such a question was posed. Data (N > 2000) which consisted of responses from students (grades 11 and 12) from across Canada yielded interesting results. Approximately 28 percent saw science as a body of knowledge; 24 percent defined it as exploring the unknown; 12 percent as improving the world; and 19 percent as undefinable. A little over 10 percent defined science as being strictly applied, and consisting of technological advancements. Only 2 percent defined science as a social institution. A small percentage did not respond or felt that no choices fit their viewpoint. One might expect that a large percentage of students defined science as a body of facts, or as an inquiry process (exploring the unknown), but what can we make from nearly one out of five students describing science as undefinable? Has science been portrayed in conflicting ways? Have these students had little or no experience with science?

Over the years, research on students' conceptions of the nature of science has shifted from making use of primarily quantitative methodologies to qualitative ones. Interestingly, however, one of the earliest studies was qualitative in nature. Mead and Metraux (1957) collected a nationwide sample of 35,000 essays on the topic "What do you think about science and scientists?" They concluded that students believed that scientific knowledge is absolute and that science has the primary goal to uncover truth.

In the 1960's the most widely used pencil-and-paper assessment of students'
conceptions was the Test On Understanding Science (TOUS) (Cooley & Klopfer, 1963). The TOUS consisted of 60 multiple-choice items with four alternatives per item. The test was developed at the Harvard University Graduate School of Education and focused on three major areas of understandings regarding the nature of science, including the scientific enterprise, scientists, and the methods and aims of science. Lederman (1992) reports that findings from research in the 1960's and 1970's, using the TOUS instrument, concluded that student understandings of the scientific enterprise were lacking. Meichtry (1993) also concluded that research findings have consistently shown that students from all grades (grade 6 through college-level seniors) exhibit poor understandings of the nature of science. Lederman attributes those poor results to the lack of adequate science instruction.

However, the TOUS instrument was not utilized without criticism. Lederman et al. (1997) report that the TOUS loaded strongly on a verbal factor in a factor analysis, and the complexity of some test items obscured the meaning of those items for secondary school students. They state, "It (TOUS) was an excellent beginning for those interested in assessing understandings of the nature of science" (p. 9). However, they conclude the TOUS is inappropriate as a sole assessment instrument for the study of an individual's understanding of the nature of science.

Another instrument developed to assess precollege student understandings of the nature of scientific knowledge was the Nature of Scientific Knowledge Scale (NSKS). This instrument contained 48 items in a five item Likert-scale format. This supposedly objective test (Lederman et al., 1997) includes the assessment of six
subscales of the nature of science. These subscales, which were partially derived from the work of Rubba and Anderson (1978), served as the model of the nature of science that the test evaluates, and purport that science is amoral, developmental, parsimonious, testable, creative, and unified.

Using the NSKS, Rubba (1977) concluded that 30 percent of the students at a large midwestern high school believed that scientific research leads to knowledge which is incontrovertible, absolute truth. Regarding a follow-up study using that instrument, Meichtry (1993) states, "Students did not understand the nature of science well enough to appreciate the tentative nature of scientific knowledge" (p. 435). In addition, Meichtry reports that an extensive assessment of student conceptions of the nature of science was performed as part of Project Synthesis (Welch, 1981). She notes that, once again, in-depth understandings of the nature of science were not exhibited by students. Lederman (1992) notes that the overwhelming data that illustrates that students do not possess satisfactory conceptions of the nature of science is particularly significant when one considers the wide variety of methods and instruments used in researching this area. In a later study, Lederman et al. (1997) discuss 25 separate instruments designed to assess various aspects of the nature of science. They conclude, "We have taken paper and pencil assessments about as far as they can be expected to go" (p. 27). They support using a variety of methodologies to assess understandings of the nature of science.

Science education researchers have done just that. More recently, researchers have tended to make use of interview techniques rather than quantitatively oriented...
instruments to collect data on understandings of the nature of science. Unfortunately, there are few qualitative studies which focus on student conceptions of the nature of science. Most of the studies which make use of qualitative methods focused on teacher conceptions (Brickhouse, 1990; Duschl & Wright, 1989; Gallagher, 1991).

In one student-focused qualitative study, Griffiths and Barman (1995) interviewed 96 high school students, 32 each from Australia, Canada, and the United States. In probing for general views of students, they asked such questions as: What is science? What does doing science involve? What is a scientific method? Is science different? and How does science change? In addition, they specifically questioned students about scientific facts, posing questions such as: What makes a particular fact scientific? and Are scientific facts open to question? Although their results show some variation between countries, they generally concluded that students had conflicting or vague views regarding the nature of science. Interestingly, in response to the question "Is science different?" they report that an overwhelming majority of the students were quite positive that science is "different" from other areas. However, they state that when the follow-up question "If so, how?" was posed, the reasons were so varied and unclear that it was not even worth classifying the responses.

Clearly these results demonstrate that although students may articulate some level of understanding of the nature of science, that understanding in many cases may be incomplete or lacking. It is encouraging that students identified science as one way of knowing that may differ from other ways, but disappointing that students found it difficult to describe what those differences might be. Griffiths and Barman (1995)
conclude that the usefulness of an education in science is restricted when the nature of science itself is poorly understood.

Results from both the qualitative and quantitative studies over the past several decades clearly demonstrate that student conceptions of science is varied and perhaps unclear, and much work still needs to be done to further describe student understandings of the nature of science. A long-term, descriptive study will provide considerable insight into student's actual beliefs. Specifically, research that describes, in rich detail, conceptions of the nature of science which students develop through participating in project-based models would contribute significantly to the research base.

A Model of the Nature of Science

Lederman (1996) states that among science educators there exists no consensus about the "true" nature of science. Meichtry (1993) also notes that there is apparently no standardized definition for either the nature of science or scientific knowledge. The definitions that exist, she concludes, are varied and multifaceted. In a recent meeting of the National Association of Research in Science Teaching, it was proposed that natures of science might be a more appropriate designation than merely nature of science. The consensus was that "natures" provided for a range of acceptable but often diverse definitions of science. In earlier work, Lederman (1992) defined the nature of science as "the values and assumptions inherent to science" (p. 331), so it seems quite appropriate that there should exist a range of satisfactory meanings to describe this
A standardized definition of a fully formed understanding of the nature of science for precollege students, especially *precise criteria*, has been lacking from many research studies (Lederman, 1986). Therefore, in an attempt to remedy this apparent lack of criteria to be used when examining student conceptions, the following model was developed for use in this study. Throughout this work, "fully formed" or "complete" is utilized to imply that student beliefs were sufficient or satisfactory when compared to the premises of the model. It does not imply that student conceptions could not develop further beyond the model. In contrast, "partially conceived," "incomplete," or "not fully formed" describes student understandings which are not sufficient when compared with the model.

This model was designed to serve as criteria by which student conceptions may be interpreted as fully formed or not fully formed, and was not designed to serve as a model for scientists, philosophers, and science educators. Such a model would likely be substantially more complex, and perhaps not appropriate for precollege students. In a recent paper, Abd-El-Khalick, Bell, and Lederman (1997) conclude that most disagreements about a definition of the nature of science are irrelevant to K-12 instruction. They state, "The disagreements that continue to exist among philosophers, historians, and science educators are far too abstract for K-12 students to understand and far too esoteric to be of immediate consequence to their daily lives" (p. 3). Similarly, Matthews (1998) proposes modest goals when teaching the nature of science and concludes, "It is unrealistic to expect students or prospective teachers to become
competent historians, sociologists, or philosophers of science" (p. 168). Perhaps it is fitting to think of this model as merely one suitable model of the natures of science that currently exist, precisely, a model geared toward K - 12 education.

For this study, when examining student conceptions of the nature of science, they were explored with regard to the broader definition proposed by Meichtry (1993) and others, that included yet distinguished between the nature of the scientific enterprise and the nature of scientific knowledge. Ideas distilled from the pilot study, science education and philosophy of science literature, national science standards, discussions with scientists, and personal experiences engaging in the scientific enterprise have contributed to this model. The characteristics or premises which define the nature of the scientific enterprise include:

1.) The universe is open to human description, classification, and understanding through scientific exploration.

2.) This scientific exploration attempts to explain and predict phenomena, compare theories, check on previous results, and generate new questions.

3.) Logic, imagination, curiosity, and serendipity contribute to scientific exploration.

4.) Scientific activity is a social activity conducted by individuals who are influenced by both cultural and personal factors.

5.) Questioning, data collection and analysis, drawing of conclusions, and communication are the major phases which characterize the scientific endeavor.
With regard to the nature of scientific knowledge itself, the following characteristics define this second significant aspect of the nature of science:

1.) Scientific knowledge demands evidence, and is testable through the scientific enterprise.

2.) Scientific knowledge cannot provide complete answers to all questions.

3.) Scientific knowledge is tentative, developmental, and subject to revision.

A further clarification of these eight premises is provided as follows.

**First Premise - Scientific Enterprise** - "The universe is open to human description, classification, and understanding through scientific exploration." This general premise sets the stage for the entire notion of scientific exploration. It implies that humans have at least some capacity to classify and understand the universe in which we live, and that we have the interest to pursue that monumental task. It also claims that the universe is potentially open to human classification and understanding. This sentiment is supported by AAAS (1989) in their Scientific World View, in which they state, "Scientists believe that through the use of intellect...people can discover patterns in all of nature. Science also assumes that the universe is...a vast single system in which the basic rules are everywhere the same" (p. 25).

In addition, we must still consider science as merely one way of coming to know the universe in which we live, therefore a recognition that the universe may be described or explored in ways other than those which are scientific is also appropriate. For example, spiritual inquiry differs from scientific inquiry. Moore (1985) noted that scientific knowledge is derived from observation and/or experiment, and must be
verifiable. To develop spiritual knowledge about the universe, one may merely rely on faith.

Describing, classifying, and ultimately understanding the universe through any mode of inquiry are human endeavors, and I believe it is impossible to entirely separate the knower from the known. As a result, there will always be a degree of subjectivity when exploring the universe, including through science which is often declared to be an objective undertaking.

Since this first tenet sets the stage for the subsequent premises, at this point I will briefly discuss the philosophical underpinnings of this model. Garrison and Bentley (1990) write that the philosophy which implicitly frames much of the current practice in science is positivism. They write, "Positivism is the idea that universal natural laws or principles may be induced with certainty from an empirical-experimental foundation" (p. 189). Similarly, Alters (1997) defines positivism as allowing experiment and observation to uniquely determine which may be a correct theory. Positivism assumes a clear separation between the knower and the known, while denying any role of subjectivity in the development of objective knowledge. On the other hand, Garrison and Bentley (1990) describe postpositivism as asserting that universal laws can never be induced with certainty. They write, "Theories and values cannot be entirely separated from facts; there is an element of subjectivity in all objective statements. Experience is theory- and value-laden" (p. 189). My model rests upon a postpositivistic philosophical foundation, although is not anti-scientific. I believe we can come to know about our universe through scientific exploration.
This first premise claims the universe is open to description, classification, and understanding through scientific exploration, and stresses the human role in that process. The main point of the first premise is that we have at least some capacity to classify and understand the universe in which we live, but perhaps even more importantly, that we have the interest and desire to do so.

Second Premise - - Scientific Enterprise - "This scientific exploration attempts to explain and predict phenomena, compare theories, check on previous results, and generate new questions" attempts to further clarify the notion of scientific exploration by stating several major goals or objectives of this enterprise. Explaining and predicting phenomena are at the heart of the notion of scientific exploration and discovery. Explaining phenomena, whether they be biological, chemical, physical, or most likely an interaction of these, is quite simply what scientists do. Explaining is a broad notion and may include describing physical attributes of phenomena or various processes associated with certain phenomena such as heat transfer or photosynthesis.

Prediction may make use of scientific models, such as global carbon budget models (Houghton & Skole, 1990), to make various projections regarding phenomena. In this case, the phenomena being projected is essentially the carbon cycle for the world.

Additionally, this precept states that science also compares theories. For this model, theories are what is generated following data collection and analysis, and may be thought of as a current or working explanation of certain phenomena. Theories differ from hypotheses, which will be discussed later. This premise states that the
scientific enterprise checks on previous results. That is, once phenomena are explained through theories, scientists have the responsibility to critically revisit and examine those theories, and ultimately judge the quality of the explanations contained within them. Theories, or explanations of phenomena, if proved time and time again in all contexts may be considered scientific laws. It is important to note that the deliberate inclusion of the word "attempts" was used in this premise to ensure that the notion of science having difficulty in explaining phenomena is not only possible, but often probable. Which, in part, explains why there are so few scientific laws and why theories or explanations often evolve, which will also be discussed in more detail later.

Finally, in defining science, this premise states that new questions are generated as a result of conducting scientific work. At the conclusion of a study, sometimes more new questions remain than were addressed in the original work.

Third Premise - Scientific Enterprise - The third premise states, "Logic, imagination, curiosity, and serendipity contribute to scientific exploration." This tenet was included to ensure that a "realistic" notion of the scientific enterprise is portrayed in this model. Although logic and intellect are often considered to be the cornerstones of scientific exploration, and in many cases they are, there are other factors which contribute to the scientific enterprise.

Imagination and curiosity may be thought of as complimentary to logic. Without the desire and ability to wonder about various phenomena of our universe, I would argue that we would have precious little to focus our intellect toward. In addition, serendipity is a factor that warrants inclusion in this model, although I
believe it is rarely discussed in a scientific context. My own experiences, however, indicate that this factor in combination with the prepared mind can sometimes set the stage for an entire scientific study (Moss, Rock, et al., in press). It is important to note that serendipity in no way diminishes the need for logic, imagination, or curiosity.

**Fourth Premise - - Scientific Enterprise** - "Scientific activity is a social activity conducted by individuals who are influenced by both cultural and personal factors" is a critical premise which states that the scientific enterprise does not operate within a social vacuum, but one which is inexorably tied to individual and cultural phenomena. The NRC (1996) describes science as a "human endeavor" (p. 108), and this precept attempts to capture several dimensions of that notion.

Many cultural/social factors affect the scientific enterprise. Societal needs or wants, such as cures for diseases, often dictate which scientific research receives funding. This funding may stem from the government or private sources. When science is conducted by the private sector it is often done for profit. Although individuals can choose their own field of study, scientists sometimes have little choice over precisely what they work on because of the influence that societal needs or desires have over what research should be pursued.

Additionally, this precept addresses the personal dimension of the scientific enterprise. This dimension deals with bias, judgement, and other factors outlined by Martin and Brouwer (1993) which affect any individual scientist on any given day. It implies that although objectivity may be one goal of scientists as they participate in the scientific endeavor, that goal is ultimately impossible to fully reach.
When discussing the social nature of the scientific enterprise, Kelley, Carlsen, and Cunningham (1993) write, "Studies in the...sociology of science have helped redefine science from (the) objective, impartial certification of knowledge to a socially constructed enterprise shaped at many levels by human values, beliefs, and commitments" (p. 207). As a result, the very needs of individuals and the society will influence the direction science will take.

Fifth Premise - - Scientific Enterprise - The final premise which characterizes the scientific enterprise is one that is, in part, derived from the pilot study and outlines the phases of the enterprise itself, and is more commonly known as the scientific method. It states, "Questioning, data collection and analysis, drawing of conclusions, and communication are the major phases which characterize the scientific endeavor." For this study, a key element with regard to the nature of the scientific enterprise is the notion of questioning. Although there are many varieties of questions which characterize various disciplines, asking and answering scientific questions is at the heart of the nature of the scientific enterprise and therefore central to the nature of science itself. Asking scientific questions may involve laying back on a starry night contemplating the wonders of the universe, or it may be a more systematic way of investigating gaps in our current knowledge. In other words, it may be a guiding question which can serve to orient one's thinking toward a scientific framework or it may be a researchable question that lends itself to other phases of the scientific enterprise, such as scientific data collection and analysis. Answering questions scientifically may involve brainstorming reasons to explain an observed phenomena or
it may involve conducting a controlled experiment to establish causality between
variables.

Additionally, it is possible for questions to be both scientific and non-scientific. For example, one could pose the question, "Is there life after death?" One could examine this question from a spiritual perspective in which one contemplates the eternal nature of the soul, or conceivably one could pursue this question via a scientific framework in which empirical tests are developed (none such tests are proposed here) for the purpose of examining this question. The context of a question, including how it is pursued, will help determine if it is scientific in nature. Therefore, how one thinks of a question within the broader context of pursuing that question can influence how that question is perceived, scientifically or non-scientifically. That is, scientific questions lead to inquiry within the content domain of science.

The formulation of a scientific question is a complex activity, and for this model includes both observing and subsequently developing a hypothesis. As stated earlier, observation might include stargazing or a more systematic way of looking at the world. In any event, observations help create the foundation for scientific questions by identifying what phenomena might be worth studying. A hypothesis is merely an educated guess of the answer to a scientific question. A hypothesis, in part, serves to aid in the formulation, or re-formulation of a question. Once a scientist has developed a guess of what the answer may be to his or her question, he or she may wish to reconsider that initial question after evaluating the appropriate course of research to test that hypothesis. Observing, hypotheses, and formulating researchable or guiding
scientific questions are closely tied, and for this model considered the first phase of doing science, referred to as *questioning*.

The next major category within the scientific enterprise is termed "data collection." This category includes designing an experiment and making measurements, all the while considering such concepts as accuracy and precision. It may also involve learning to use scientific equipment or learning to follow scientific protocols that one may utilize in the process of collecting data in support of pursuing a scientific question. It involves the actual development and implementation of a suitable or appropriate research design. An appropriate design is one which may include such notions as validity and reliability, but most importantly the design will lead to the generation of new data that will help answer the researchable question. Such new data may contribute to the explanation of certain phenomena, hence a theory, or serve to revisit and verify or refute an established theory.

Data analysis is defined as searching for patterns or important information contained within the data. Data may be quantitative or qualitative in nature. Analysis of quantitative data often involves a statistical comparison of findings. Descriptive statistics aim to outline the general characteristics of data by highlighting such parameters as maximum and minimum values or means. There are also a variety of statistical tests that specifically allow one to search for trends or patterns in data (Wiersma, 1995). For example, a comparison of means of various measurements may involve the use of $t$-tests. Data analysis may also involve the use of qualitative or non-numerical data, in which no variables are manipulated and no statistics are
presented. However, through qualitative description, an answer to a scientific question can also be sought. For example, one may wish to investigate the anatomical differences between plant species. The analysis of that data may describe the presence and placement of various anatomical features of the plants under study.

An important aspect of data analysis is that it ultimately may lead to a conclusion in the scientific research process. "Drawing of conclusions" is the next step within this model of the scientific enterprise. Following data analysis, one might ask, "Was a definitive conclusion reached?" When posing this question, one may consider data quality issues, such as data accuracy, which may require revisiting the research design. A conclusion following the data analysis may be thought of as an answer to the research question. If the question was not answered, identifying future areas of study becomes an important component of this phase.

The final phase characterizing the scientific enterprise is "communication." The reporting of results or conclusions is "formal" communication. This may be oral or written communication of scientific findings. It may be in the popular press or electronic media, or may be through a more "scientific" context such as peer review publications or conference presentations. It allows other individuals to critically examine the conclusions of a study, and potentially can lead to further work in that field by sparking new questions or lines of research that the original author(s) may not have considered.

Communication involves sharing of one's scientific work for the purpose of the advancement of knowledge, therefore "informal" communication of scientific ideas
may occur at any point throughout a research study. It can either serve to help to formulate a question, develop a research design, or discuss any aspect relevant to the ongoing work during the course or even following a study. Informal communication occurs with anyone whom the researcher discusses his or her work.

In many modern contexts, scientific communication is part of a competitive environment. The effective demonstration of one's body of work can lead to the opportunity of future work in that field through the attainment of grants or funds to continue that work. Therefore, there is an ethical component to the communication of findings. Regarding this area, AAAS (1993) writes, "Deliberate deceit is rare and likely to be exposed by the scientific enterprise itself" (p. 20). When communicating scientific results, ideally, the perceived limitations of the findings should be made explicit.

First Premise -- Scientific Knowledge -- The second major component of the model of the nature of science deals with the nature of scientific knowledge itself. The first premise states, "Scientific knowledge demands evidence, and is testable through the scientific enterprise." For most cases, this implies that scientific knowledge differs from other forms of knowledge in that some form of empirical evidence exists to justify the knowledge as scientific. That empirical evidence must be gathered via the scientific enterprise. Note that the nature of scientific knowledge cannot be separated from the nature of the scientific enterprise with regard to the postpositivistic foundation described earlier. The premises which define the scientific enterprise are in a sense precursors to the premises for the nature of the knowledge itself. The human
element which characterizes the scientific enterprise, or the process of science, also characterizes scientific knowledge, or the product of science.

There are researchers in various fields of science who deal with only theoretical problems in which little or no empirical evidence exists. In these cases, although concrete evidence may not exist, the original question and theoretically-based scientific enterprise that is employed in answering it, should still follow a path that adheres to scientific ways of thinking. Theoretical scientific knowledge is knowledge that still attempts to explain and predict phenomena in our universe through scientific questioning and data analysis. Perhaps one way to think of it is that scientists make greater use of their imagination, in conjunction with their logic and curiosity, when pursuing theoretical questions.

Second Premise - Scientific Knowledge - "Scientific knowledge cannot provide complete answers to all questions." This tenet states that even scientific knowledge itself, applied to scientific questions, can often not answer those questions fully. Scientific knowledge may often be incomplete.

Third Premise - Scientific Knowledge - The final premise of this model states, "Scientific knowledge is tentative, developmental, and subject to revision." The tentative nature of scientific knowledge has been discussed by many science education researchers (Cothram & Smith, 1981; Kimball, 1968). This precept clearly suggests that scientific knowledge is not "fact" or "truth" for all time. The developmental and revisionary nature of scientific knowledge helps to clarify the tentative nature of that knowledge. The tentativeness of scientific knowledge must be thought of along a
continuum from ephemeral to durable, sometimes lasting for hundreds of years and other times being replaced quite quickly. In each case, however, new knowledge is built upon prior knowledge. Scientific knowledge is not tentative in that it can be dismissed by a whim, it is tentative in that it can be replaced by new knowledge developed through the scientific enterprise, that is, it is revised and as such may be considered developmental in nature.

Kuhn (1970) recognized the relative transience of knowledge. Utilizing a framework developed by Kuhn, Hunter and Bodner (1997) discussed scientists' beliefs about the nature of science, stating "(the scientists) participate in science as a way of knowing about the universe, but they do not expect current ideas to be forever seen as correct...science progresses...therefore current theories must inevitably be replaced" (p. 9-10). This model supports those notions.

Summary

The development of an understanding of the nature of science by precollege students is widely advocated as an outcome of science instruction, because an understanding of the nature of science has been identified as an important learning goal for the attainment of scientific literacy. There has been research on various aspects of the nature of science, including the examination of student conceptions in this area. Results from both the qualitative and quantitative studies demonstrate that student conceptions of the nature of science are varied and perhaps unclear. Work still needs to be done to further describe student understandings of the nature of science, especially if developing a fully formed understanding of the nature of science.
continues to be a key element in attaining scientific literacy. Specifically, research that tracks student understandings of the nature of the scientific enterprise and the nature of scientific knowledge over time have been lacking.

Meichtry (1993) defines the nature of science within a framework that distinguishes the nature of scientific knowledge and the nature of the scientific enterprise. This distinction has provided the basis for the development of a model of the nature of science which was used throughout this research study. This model of the nature of science was developed to address a weakness in the literature dealing with the nature of science that was identified by Lederman (1986). That weakness being that precise criterion outlining what are believed to be a fully formed conception of the nature of science are lacking from many research studies.

This postpositivistic model includes notions of the personal and social nature of the scientific enterprise, as well as the tentative nature of scientific knowledge itself. I am not proposing that this model serve as a standardized definition for the science education community, only as a framework by which student conceptions of the nature of science were examined throughout the course of this study. This model may be thought of as my own understanding of one of the natures of science, specifically one I believe to be appropriate for secondary school students.

**Project-based Learning**

When one considers the use of projects in the classroom, one should begin by examining what one believes to be the educational purposes of schooling and
determine if the use of a project-based curriculum meets any of those purposes. Renner and Marek (1990) summarize the 1961 Educational Policies Commission (E.P.C.) statement of the purpose of education which may be succinctly stated as the *ability to think*. Although this is, of course, an extremely broad view, it captures the essence of today's science reform efforts. For example, AAAS (1989) advocates active approaches to learning that will enable students to not only learn information, but use that information in problem solving scenarios throughout their lives. However, we must not consider our educational goals for students without considering how they learn. Although it is likely that we will never fully understand all of the complexities of how humans learn, there are currently theories of learning which help explain some of the cognitive interactions between people and our world. Constructivism, as outlined by Phillips (1995) and numerous others, is one such theory that has greatly influenced science instruction (Appleton, 1997; Matthews, 1996). Specifically, conceptual change (Linder, 1993; Posner et al., 1982; Southerland, 1997) has been proposed as one mechanism by which learners construct meaning in science classroom settings.

**Conceptual Change**

Constructivism may have its roots in the early works of Socrates (Brooks and Brooks, 1993), but how does one define constructivism, or constructivist learning? Volumes have been written in an attempt do to just that, but a simple definition may be that *we construct our own understandings of the world in which we live*. The idea...
seems simple enough, however there has been extensive scholarly debate over much of what constructivism implies about learners and the reality of our world.

Constructivism has been defined as a model of learning as well as an educational doctrine (Suchting, 1992). A constructivistic learner implies an active learner who is making connections between prior life experiences in an attempt to understand our world.

One mechanism by which constructivism can be carried out is that described through conceptual change theory (Driver & Scanlon, 1988; Linder, 1993; Posner et al., 1982; Southerland, 1997). Early conceptual change theory arose from the alternative conceptions movement that rapidly expanded during the 1980's (Treagust, Venville, Harrison, & Tyson, 1997). Posner et al. (1982) described their conceptual change theory as explaining the methods by which conceptual frameworks are constructed and modified, such as when a learner captures new concepts or restructures existing concepts. This theory usually deals with key or central concepts and explains that conceptual change occurs when learners recognize shortcomings in their current understandings and discover or are shown a more plausible, intelligible alternative.

Piaget refers to the process of moving from a mental state of equilibrium to disequilibrium and back to equilibrium as equilibration (Mallon, 1976). Conceptual change occurs as a result of a similar process as that of equilibration (Lawson, 1994). In fact, Stofflett and Stoddart (1994) explain how the theoretical framework for conceptual change is based, in part, on Piagetian constructivism. According to Posner
et al. (1982) conditions necessary for conceptual (change) equilibrium to take place are: (1) data that are inconsistent with prior ways of thinking; (2) the presence of alternative conceptions; and (3) sufficient time and motivation to compare alternative conceptions and their predicted consequences with new evidence. Conceptual change theory, although not necessarily developmental, emphasizes the importance of students' prior knowledge.

Similarly, in later work, Shiland (1997) describes conceptual change as usually requiring the following elements: (1) students become aware that their conceptions cannot address a particular problem; (2) students' opinions should be further developed through demonstrations, experimentation, and questioning; (3) students' opinions are shown to be inadequate; (4) new concepts are introduced; and (5) further applications of the new concepts are demonstrated. He believes this rational model of learning can, in part, describe the conditions necessary for students to go from one set of beliefs to another. Like in Posner's et al. (1982) earlier model, older concepts are completely replaced by newer ones.

Southerland (1997) also defined conceptual change as a "process of rational comparison" (p. 6). She notes conceptual change is often thought of as representing wholesale change motivated by the learner's dissatisfaction with the pre-existing condition. However, she concludes from a study with a high school biology class regarding evolutionary theory, that the conceptual change experienced by students were not simplistic nor linear. In her study, she found four models of conceptual change, and refers to them as patterns, which are: incremental, wholesale, cascade, and
dual conceptions.

In incremental changes, the learner employs new terms within a previously constructed explanation. She writes, "In many cases of such changes, this was not reflective of a full, scientific understanding, but seemed to reflect a rote application of the term" (p. 7). Wholesale changes followed the pattern described by Posner et al. (1982) in which prior conceptions were completely discarded in favor of new conceptions. Cascade changes occur when a change in one conception proceeds a number of later changes in conceptions which are very closely related. Finally, dual conceptions exist when a learner holds and applies two logically incompatible conceptions for the same phenomena.

Southerland (1997) describes these mechanisms as more "interactionist" in nature than many older conceptual change models, and writes, "...different learners may learn the same content through different pathways while employing different processes of change" (p. 21). Further research is needed in this area, however she concludes earlier versions of conceptual change models are too narrow to include what often may happen with our students when learning science. She states, "...while wholesale conceptual change can occur in the manner described by Posner et al. (1982), this is not the only avenue of knowledge restructuring that occurs in our classrooms" (p. 21). She argues for an expanded role of the learner's prior knowledge such as personal characteristics, including deeply held, culturally and experientially influenced understandings, if we are to truly model a broad range of science learning.

But how can/should one describe students' prior knowledge? Terms such as
misconceptions and alternative conceptions have been utilized. Demastes-Southerland (1993) explains that each term implies a slightly different epistemological base. Misconception implies there is little value to students' conceptions, implying that they simply need to be corrected. Alternative conceptions, she states, implies a contextually based, rational explanation. Succinctly stated, this term implies more respect for students' views and difficulties in their own learning, and is one that I prefer.

Therefore for this study, when describing student conceptions of the nature of science over an entire school year, conceptual change theory (Southerland, 1997) served as the theoretical framework by which I examined student understandings. I examined student conceptions with regard to both the role of the learner's prior knowledge, including their experientially influenced understandings of the nature of science which they received outside of formal schooling, as well as their experiences they received during participation in project-based classes. During ongoing data analysis, close attention was paid to incremental changes in which ideas or vocabulary from science lessons or activities were incorporated into student conceptions without students having a full or clear scientific understanding of their explanations. In addition, an earlier version of conceptual change theory (Posner et al., 1982) also influenced the interpretation of data. When examining student conceptual change over the entire year, I considered students' dissatisfaction with their understandings of the nature of science along with the presence of any alternative conceptions, in this case new models of the nature of science, that existed which may have influenced student beliefs.
Lavoie (1997) concludes that changing students' beliefs about science is not an easy task. He notes conceptual change teaching strategies should involve a constructivist approach, and cites Seymour and Longden (1991) by quoting:

Teaching approaches should shift away from a 'transmission' [sic] approach to learning, in which information is simply passed from teacher to pupil and in which the pupil employs rote learning to memorize subject material...such an approach necessitates a change in the role of the teacher from a purveyor of knowledge to a facilitator of learning, in which the central responsibility for learning is transferred to the child. (p. 183)

But the question still remains regarding which model of instruction is best for minimizing didactic approaches, while at the same time transferring some of the responsibility for learning to the student. Perhaps project-based models may help teachers facilitate this type of instruction.

Project-based Models

Katz & Chard (1989) note project-based models of instruction have been utilized in K - 12 education throughout the twentieth century. They state that in the United States, the idea of learning through projects originally gained wide popularity in the 1920's after this approach was strongly advocated by John Dewey. In a later work, Dewey (1938) wrote on what he considered to be progressive education versus traditional education. He defined traditional education as "...the bodies of information and of skills that have been worked out in the past; therefore, the chief business of the school is to transmit them to the new generation" (p. 17). He further defined such bodies of information as "static" and as a "finished product." In contrast, he defined progressive education in terms of experiences that the students had. However, he
wrote, "The belief that all genuine education comes about through experience does not mean that all experiences are genuinely or equally educative" (p. 25).

Brusic (1992) cited educational philosopher Alfred Whitehead who also wrote on the ideas of experience and education in the early part of this century. Whitehead (1929) wrote, "First-hand knowledge is the ultimate basis of intellectual life. To a large extent book-learning conveys second-hand information, and as such can never rise to the importance of immediate practice" (p. 79). Brusic also notes that an experiential approach to education has undergone a recent revitalization through the use of technology in the classrooms. She states modern technology programs highlight this first-hand knowledge approach by actively engaging students in real world problem solving activities.

Modern experiential education has been defined in numerous ways (Chapman, McPhee, & Proudman, 1992). Chapman et al. note experiential education can not be thought of simply as a particular set of activities such as ropes courses or canoe trips which have been typically associated with this present day model of instruction. Ultimately, they define experiential education as "An approach which has students actively engaged in exploring questions they find relevant and meaningful...students can draw valid and meaningful conclusions from their own experiences" (p. 18). This definition is certainly in-line with Katz's (1994) definition of a project-based approach in which she states that a key feature of projects is that they are research efforts deliberately focused on finding answers to questions. Additionally, in earlier work, Katz & Chard (1989) note that in project work students should share the accountability...
with teachers for learning and achievement. I believe Dewey would be both pleased and dismayed with present day project-based instruction. Pleased in the sense that project-based curricula address many of the concerns regarding the opportunity for quality educational experiences that he wrote about over 50 years ago, and perhaps disappointed that there seem to be so few classes which follow this so called "progressive" model.

One key feature of project-based models is that they may allow students to make choices at several levels throughout the duration of the project (Katz & Chard, 1989). Whether the choice be procedural, such as choosing a topic for study, or perhaps more analytical as when students decide upon an appropriate course for data analysis, making choices can often involve group interaction. This interaction can either be student to teacher or peer to peer, in which students work collaboratively on making decisions. This social construction of knowledge, such as decision making in groups, has been widely studied (Hassard, 1990; Sharan & Sharan, 1992). Similar to previous definitions proposed for project-based instruction, Sharan and Sharan define group investigation as "a method for classroom instruction in which students work collaboratively in small groups to examine, experience, and understand their topic of study" (p.1). Specifically regarding learning in science, Alexopoulou and Driver (1996) stress the importance of group discussion. They conclude that the dynamics of group interaction can have a significant effect on the quality of that collaboration.

AAAS (1989) indirectly supports a project-based approach, which includes the notions of experience and group interaction, when they state that teaching should be
consistent with the nature of scientific inquiry. They write:

Sound teaching usually begins with questions and phenomena that are interesting and familiar to students...students need to get acquainted with the things around them - including devices, organisms, materials, shapes, and numbers - and to observe them, collect them, handle them, describe them, become puzzled by them, ask questions about them, argue about them, and then try to find answers to their questions. (p. 147)

Project-based instruction can take on various designs. Morgan (1983) argues it is essential that the aims and assumptions of project-based learning are made explicit.

Morgan defines project-based learning as:

An activity in which students develop an understanding of a topic or issue through some kind of involvement in an actual (or simulated) [sic] real-life problem or issue and in which they have some degree of responsibility in designing their learning activities. (p. 66)

He points out that there is great diversity in which responsibility and autonomy is given to students. He concludes that during project-based learning, students are experiencing their learning in an active mode, rather than a relatively passive one, which is often implicit to traditional didactic teaching. This active mode is one in which a change from teacher-centered toward student-centered classrooms can become more common (Dwyer, 1994). The teacher as facilitator of the construction of students' own knowledge is favored, as opposed to the teacher being solely a source of knowledge and transmitting that knowledge to students. Wolk (1994) claims project-based instruction has positive effects within the science classroom. He writes, "Students are into their work so intently, so genuinely...they are constantly interacting with one another. One student conducts a science experiment...and three other children come to watch" (p. 43).
Krajcik, Blumenfeld, Marx, and Soloway (1994) describe their collaborative work on project-based instruction with middle school teachers. They also conclude that project-based instruction, grounded in constructivist theory, affords many possibilities for transforming classrooms into active learning environments. Students' investigations should be centered around a driving question, which they believe should be authentic and encompass substantial content. They point out that similar discovery learning approaches from the 1960's were not as widely accepted as they might have been because of the top-down, transmission model of teacher change that was advocated. Today, we recognize that such sweeping changes in the classroom are not so easily achieved. Regarding science education reform, AAAS (1989) recognizes that the effort must be inclusive and sustained for us to avoid the quick-fix approaches from the past.

Eisenhart, Finkel, and Marion (1996) re-examine scientific literacy as a goal for the current science reform movement, and although they describe the vision of scientific literacy as broad and inclusive, they conclude that it is being implemented in narrow and conventional ways. In an effort to outline alternate routes to scientific literacy, they describe several models, including the Foundations of Science (FOS) program, in which scientific literacy may be achieved. The FOS program, which is indeed project-oriented, was initially based on the Global Rivers Environmental Education Network (GREEN) program (Mitchell & Stapp, 1994). It was developed by three science teachers at a midwestern public alternative high school working closely with researchers at the University of Michigan. They state FOS, a project-based environmental monitoring program, encourages students and communities to work
together to tackle an environmental problem. They adopt a local creek, collect and analyze data regarding the quality of the creek's water, and communicate results through written reports which are submitted to local environmental agencies and, in addition, make presentations on a local cable television station. Eisenhart et al. (1996) hope a project-based model such as this will foster socially responsible scientific literacy, but the question still remains: Can project-based models provide teaching and learning opportunities that meet our educational purposes and the goals of science reform? Specifically, can project-based instruction help foster an understanding of the nature of science for students? This research was undertaken to address that important question.
CHAPTER III

METHODOLOGY

The guiding research question for this study is, "What conceptions of the nature of science do precollege students hold and develop over the course of an academic year?" It is through qualitative methodologies that the complex notion of the nature of science was examined. Qualitative educational research has its beginnings in cultural anthropology, more commonly known as ethnography. Erickson (1984) writes that ethnography is not a reporting process guided by a specific set of techniques, but an inquiry process carried out by human beings and guided by a point of view that derives from experience in the research setting. Ethnography is about people. Wolcott (1988) notes that the ethnographer, the person, is the research instrument, and writes:

That instrument - the anthropologist in person - has been faulted time and time again for being biased, inattentive, ethnocentric, partial, forgetful, overly subject to infection and disease, incapable to attending to everything at once, easily distracted, simultaneously too involved and too detached...(p. 190)

but goes on to ask: What better instrument could we devise for observing and understanding human behavior?

Marshall and Rossman (1989) write, "One purpose of qualitative methods is to discover important questions, processes, and relationships, not to test them" (p. 43). To accomplish this, various data collection techniques are utilized in qualitative research, including: (1) in-depth, open-ended interviews; (2) direct observation; and (3) written documents, including such sources as personal diaries or program records (Patton,
1987). The emphasis in qualitative research is the describing and reporting of phenomena in words as opposed to quantifying results using numbers or statistics.

Griffiths and Barry (1993) report that in the 1960's and 1970's a number of written, objective instruments were developed through which researchers attempted to determine the status of students' understandings of the nature of science. They note one limitation of such a quantitative approach, for example administering a survey instrument using a Likert scale, is that there is a chance that students might not attach the same meaning to items as the test developers resulting in students misinterpreting or not understanding the questions. They state one could make use of a more open-ended questionnaire, but note that students' views may remain hidden because of limited information that can be acquired using this technique. Griffiths and Barry provide an excellent solution to the potential problem by stating, "One way to get around this problem is to attempt to tease out students' understandings face to face, in an interview setting" (p. 35).

Lederman, Bell, and Wade (1997) also recommend the use of qualitative methodologies to examine student conceptions of the nature of science:

What seems to be recognized is that while paper and pencil instruments can reveal something about students' views of the nature of science, they cannot tell us everything that we would like to know. Very often, the significant question is not whether a person's view of the nature of science conforms to a particular espoused viewpoint, but rather, what are the limits of the person's understandings... (p. 25)

In this passage, Lederman et al. reframe the research question regarding students' views on the nature of science toward one that probes for the limits and boundaries of student understandings, a question that is better explored through qualitative methods.
Site Selection

This study was conducted at both Woodland and Valley High Schools because results from the pilot study suggested that project-based models of instruction contributed to classroom settings in which students could readily learn about the nature of science. The project-based classes at each school emphasized various aspects of the model of the nature of science. The Project Seafarer class at Woodland focused on questioning, gathering data via library research, drawing conclusions, and communication, while the Conservation Biology class at Valley focused mainly on naturalistic ecological data collection, along with minimal data analysis and drawing of conclusions. Each school provided a context in which to examine student beliefs. Focusing on both schools also allowed further investigation into the differences between these two project-based models to see if they had any affect on students conceptions.

This study required gaining entry to two different classroom settings, which due to prior relationships established during the pilot study, posed no difficulties. Both teachers essentially provided me with unlimited access to their classrooms. This allowed me to visit each school weekly in order to observe classes over an entire school year, and in addition enabled me to attend other classes of particular interest, such as those in which students made presentations or visited field sites.

Participants

The word participants was chosen to designate students involved in this study.
based on work by Demastes-Southerland (1993) in which she supports that designation. Subject, although used by many researchers, implies a structured hierarchy in the researcher-researched relationship which connotes a power differential that, although should be recognized, could be unduly emphasized by such a designation. Interviewee implies a passive role for the participants that may not always be appropriate. Informant has negative connotations which include involvement in a subversive activity. The decision to use the word participant which may seemingly be a matter of semantics is actually an important philosophical one. Viewing the students as participants in this research helped set a tone of respect and openness for classroom observations and interviews.

Upon entering both classroom settings, building rapport with potential participants was a priority. Peshkin (1984) defines rapport as "trust," and notes that trust is earned over an extended period of time. First contact can be difficult. Experienced qualitative researchers, Langness and Frank (1981), write:

Initial contact is always difficult, mainly because one must simultaneously be both cautious and bold, and also because, whether the fear is objectively valid or not, one usually fears that success or failure is linked to first impressions. (p. 35)

The first several weeks of the school year were spent attempting to get to know the students and becoming familiar with the classroom context and dynamics.

After several weeks of participant observation, students were selected for formal interviewing based on their willingness to participate, gender, and achievement history. Purposeful sampling was sought for maximum variation (Patton, 1987). At Woodland, students who were investigating science-related questions was also a
selection criterion. This was not a concern at Valley since the entire focus of the class was science.

Each student in the classroom was given a personal and parental consent form which outlined his or her potential role in the study, especially participation in formal student interviewing. Only students who agreed to participate and who obtained parental consent were considered for participation (see Appendix A). No students selected for this study refused to take part. Students could choose to discontinue participation at any time over the course of the research project, although none did so. Pseudonyms are used to protect the identity of all participants.

Five students were selected from each class and interviewed individually for approximately 30-45 minutes each, six times over the course of the school year. At Valley High, two males and three females were selected following the observation period. Two students (one male and one female) were classified according to achievement history in science as high achievers, two students (one male and one female) as mid-level achievers, and one student (one female) as a low achiever. At Woodland High, three males and two females were selected following the observation period. Two students (two males) were classified according to achievement history in science as high achievers, one student (one female) as a mid-level achiever, and two students (one male and one female) as low achievers (See Table 1).

**Sources of Data**

Various sources of qualitative data were used in this study. The primary source
Table 1. Students Selected for Participants in the Study

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</table>

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of data were transcripts derived from formal student interviews. Other sources of data, such as student work and notes acquired through participant observation, were used to corroborate statements made during those interviews. This process of making use of two or more qualitative sources, or cross-validation, is called triangulation (Wiersma, 1995). Triangulation helped ensure observations and interpretations were accurate.

**Participant Observation**

Throughout this study, *participant* in participant observation was emphasized by frequently interacting with the students and teacher while being an active member of the classroom. Working on projects with students, helping them with work from other classes, and answering general questions about college are just a few examples of my participation in class. Although there were times in which I remained to the side of the classroom during lessons or activities, most of the time I was circulating the room and actively participating in classroom happenings while focusing my attention toward student understandings of the nature of science.

While describing the overall importance of participant observation, Taylor and Bogdan (1984) state "no other method can provide the detailed understanding that comes from directly observing people and listening to what they say at the scene" (p. 79), but recognize that interviewing in conjunction with participant observation may be a more sound methodological strategy which is better suited to answer certain research questions. Weekly participant observation enabled me to adequately document and demonstrate, through descriptive accounts, what transpired in the classroom over the
course of the academic year. In later chapters, such accounts will help provide a framework for the reader to interpret the descriptive accounts regarding students' conceptions of the nature of science. The accounts provide a context which enable the reader to gain an accurate portrayal of the classes at both the Woodland and Valley schools.

Informal interviews, which occurred throughout participant observation, were as brief as a minute or two or sometimes extended conversations with one or more individuals. The purpose was to clarify observations. These informal interviews were not recorded, although notes were taken during such impromptu discussions. Notes from observations and informal interviews were taken in a field book and reviewed regularly.

**Classroom Artifacts and Directed Journal Entries**

Classroom artifacts such as syllabi, handouts, tests or quizzes, and project guidelines were collected and examined throughout the year in order to help understand what transpired at each project-based classroom. Such artifacts contributed significantly toward generating the descriptions of a typical day for each class along with the goals and expectations outlined by each of the teachers. In addition, student work, such as completed projects, were also collected and used to gain further insight into students' conceptions of the nature of science. Student work primarily served to confirm information uncovered through the interview process. Like transcripts of formal interviews, all student work was coded based on aspects of the nature of
science outlined in the model.

Although those students who were being interviewed were asked to make monthly directed journal entries which also focused on their notions regarding the nature of science, students were reluctant to comply with this request because of their school workload. In this case, teachers supported the students, and requested that I not make this a "mandatory" activity for the participants. As a result, no directed journal entries were completed by students and I had to forgo using this source of data.

**Formal Interviews**

Spradley (1979) describes various types of interview questions, such as grand tour questions to get the interview going, and example or experience questions which are usually specific and encourage the participant to back up what he or she is saying. Both of these types of questions were used along with questions that specifically probed for definitions of specific terms or phrases that related to the students' own school work, and were designed to allow them to describe in their own words their understandings of the nature of science. Because this study was designed to uncover and describe student conceptions regarding the nature of science, every attempt was made to avoid using scientific terminology. Scientific terminology was used only if it was initially introduced by the student.

Taylor and Bogdan (1984) caution that a researcher should be non-judgmental, sensitive, and let the participant do most of the talking while gently probing and paying attention to what is said, and perhaps not said. This interviewing strategy was
followed throughout the course of the year. Students were individually interviewed for approximately 30-45 minutes each, six times over the course of the school year. Formal interview dates were: mid-October, early-December, late-January, mid-March, late-April, and late-May/early June. Interview questions are outlined in the next subsection.

**Interview Questions** - Data from semi-structured, formal interviewing consisted of audio-recorded, one-on-one student interviews which were transcribed verbatim. Although many questions were predetermined and approved in the research proposal, some were generated throughout the course of the year to follow-up on important areas for study that arose during participant observation or formal interviews conducted early in the year. White and Gunstone (1992), in discussing interviewing students in order to bring out their conceptions, state:

> The interviewer must be ready to follow-up the response of a student...since the course of an interview depends on what the student says the form and sequence of follow-up questions cannot be detailed in advance. (pp. 66-67)

Therefore, not all of the interview questions can be or were determined in advance. In addition to the proposed interview questions and those developed throughout the course of the year, follow-up questions were often generated throughout the course of each individual interview as the conversation progressed into unexpected or interesting areas.

The first interview served to primarily establish a baseline with regard to student understandings of the nature of science. This first set of questions for the first formal interview was designed to uncover students' general views regarding the nature
of science:

How much science have you taken in school?

Can you define science?

By first inquiring how much science a student had taken, I began to determine student attitudes toward science, experience with science, and whether or not they were considering science as a future course of study or career. Such data partially served to provide background information for each student. Asking students to define science, while providing appropriate examples, was perhaps the most important question of the first interview. It enabled me to gather a baseline for each students' definition of science to be used for comparison throughout the school year. Does this definition change? If so, how does the new definition differ from the previous one? Also, I was able to determine how students arrived at the definition that they currently held. Do they think of science as existing both in and out of the school setting? Is their definition one that was provided for them, verbatim, in a science classroom or was it one that they had developed in some other way?

The second set of questions for the first formal interview was designed to begin to explore the scientific enterprise, especially one aspect: questioning.

What is the scientific method?

Where do scientists get scientific questions?

Can a science question be fully answered?

What if conflicting answers are found?

Are there questions that are not scientific?
First, the students were asked if they were familiar with the scientific method. If so, could they provide examples of when they may have made use of this method? Could students name and describe the phases of the scientific method? Most importantly, did they recognize scientific questions as being paramount to the scientific method? In the detailed description of the model of the nature of science, I noted that scientific questioning is a key element of the nature of the scientific enterprise. By probing where scientists get their questions, I sought information on the social nature of science. Do scientists investigate what is of interest to them or do questions derive from other sources?

Next, I examined if participants understood the notion of a researchable question. Could they provide examples of researchable scientific questions? Are science questions narrowly focused or broad? In addition, student conceptions of non-scientific questions were examined. Do they recognize a scientific question as a different type of question than a non-science question?

The third set of questions for the first formal interview was designed to explore the next phases of the scientific enterprise: data collection and analysis.

What kind of evidence do scientists uncover to answer their questions?

How is that evidence used?

Can that evidence be incorrect?

By probing about evidence that scientists use, I was able to determine whether or not students understood that scientists often collect original data to answer their questions. By asking how that evidence (data) is used, I began to explore if they thought of data
collection as different from data analysis. How do they differ? What does analysis entail?

The fourth set of questions for the first formal interview was designed to explore the final phases of the scientific enterprise: drawing of conclusions and communication.

How do you know when you have completed a research study?

What happens at the conclusion of a scientific study?

Their conceptions of how one arrives at a conclusion in a study was examined. Did they see a conclusion of the study as answering a question? Does a conclusion lead to additional questions? Additionally, do they see communication of those results as a component of the scientific enterprise? Are they familiar with both written and/or oral forms of communication? Why do scientists communicate results?

The final question of the first formal interview deals with the nature of scientific knowledge itself.

Does science seek to find the truth?

By asking if science seeks to find truth, I was probing to determine if they believed scientific knowledge to be absolute and/or durable. Is there a correct answer to scientific questions? Is scientific knowledge tentative? Do they understand both the tentative and developmental nature of scientific knowledge, while not dismissing all of scientific knowledge as "incorrect" or "useless."

It is important to note that during various interview sessions these questions were not asked in the exact same order. In responding to the participant, the order of
the questions was changed when necessary. However, all questions for each of the first interviews were posed sometime throughout the interview process.

As discussed earlier, the following model was generated to provide a framework by which student conceptions of the nature of science were examined. Corresponding codes (scientific enterprise = SE, scientific knowledge = SK) are also shown for each premise. The nature of the scientific enterprise is defined as:

1.) The universe is open to human description, classification, and understanding through scientific exploration. (Code = SE1)

2.) This scientific exploration attempts to explain and predict phenomena, compare theories, check on previous results, and generate new questions. (Code = SE2)

3.) Logic, imagination, curiosity, and serendipity contribute to scientific exploration. (Code = SE3)

4.) Scientific activity is a social activity conducted by individuals who are influenced by both cultural and personal factors. (Code = SE4)

5.) Questioning, data collection and analysis, drawing of conclusions, and communication are the major phases which characterize the scientific endeavor. (Code = SE5)

The nature of scientific knowledge is defined as:

1.) Scientific knowledge demands evidence, and is testable through the scientific enterprise. (Code = SK1)

2.) Scientific knowledge cannot provide complete answers to all questions. (Code = SK2)
3.)  Scientific knowledge is tentative, developmental, and subject to revision. 

(Code = SK3)

Following the first interview, a core set of questions was developed that was utilized during subsequent interview sessions. These questions were focused toward uncovering student conceptions of the nature of science. Following is the core set of questions and codes utilized for this study (codes correspond to the specific premises of the model which the question addresses):

Can you define Science? SE2

Is there a common goal to all of science? Can it be achieved? SE1, SE2

Have you done any science in the last few weeks? SE2, SE5

What are some characteristics of a scientist? SE3, SE4

Where do ideas for scientific investigations come from? SE4

What guides scientific research? SE3, SE4, SE5

Does science differ between countries? SE4

If two scientists do the same research, will the results be the same? SE4, SK3

Are most scientists men or women? SE4

What do you think of when you think of a typical scientist? SE3, SE4

Do scientists work alone? SE4

What happens at the conclusion of a scientific study? SE5

What is the scientific method? SE5

Is there a most important step? SE5

Do scientists follow these steps? SE3, SE5

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Must things be proven to be scientific? SK1, SK3  How? SE5
Can scientific knowledge change? SK3
Can a scientific question be fully answered? SK2
Does science seek to find truth? SK3
Does scientific knowledge become out of date? SK3
Does older knowledge have any use? SK3

Additional questions utilized throughout the year focused on projects that the students were conducting in class. These questions were designed to uncover students' views regarding their projects and what they were learning by doing them:

Have you done any science in the last few weeks?
Are you doing any project work in other classes this year (or have you done any in previous years)?
What kinds of questions did you pose in those projects?
Are these scientific questions?
Do they differ from the questions you are generating in this class?

The lead off question is designed to revisit the notion of science. It was an opportunity to solicit a definition of science again, and identify if students view their projects as science projects. For each interview session I explicitly asked each student for their definition of science. Describing why they feel they have or have not done science provided insight into their conceptions of the scientific enterprise. Once again, I revisited the notion of scientific questioning as one aspect of the scientific enterprise by asking students the kinds of questions they had posed to guide their projects both
currently and in the past. If questions had indeed guided their projects, I inquired as to their origin. Was it a scientific problem? A teacher or student generated question? If they felt questions had not guided their projects, then I inquired how they proceeded through them to whatever conclusion, if any, they found.

Other interview questions also focused on the students' own work as well as their general conceptions of the nature of science. The questions were tailored to each individual student and the project he/she was working on at the time. Depending on the progress of each class, the various premises of the model of the nature of science were investigated at different points throughout the year. For example, if students were presenting projects, formal interview questions were more geared towards scientific communication. Follow-up questions were routinely posed and students always were asked to be clear and provide examples to support what they were saying. During all interviews throughout the year, the major points of the model were touched upon in order to determine if student conceptions had changed.

Analysis

Two sites, two groups of students, an entire year of participant observation, interviewing, and artifact collection, how does one make sense of it all? First, analysis was ongoing. Transcripts were generated throughout the course of the year and reviewed to determine important and interesting areas of investigation early in the research process. Questions for formal interviews and observations during weekly classroom visits were constantly geared toward what I perceived to be happening in
each class vis-a-vis student experiences regarding the nature of science. In this way, data collection and analysis were an interactive process leading to a portrayal of student understandings over the course of the year.

Content analysis of the transcripts was a two-step process of coding and interpretation. First, all passages were coded using codes which corresponded to the premises of the model of the nature of science. Subsequently, those passages in the transcripts dealing with various aspects of the model were interpreted to develop a snapshot (insight) of the students' conceptions of those areas at that time. For example, during an interview, if a student discussed the data collection techniques utilized throughout a project (e.g., by listing those techniques), that passage in the transcript was coded "data collection (SE5)." Once coded, if it was interpreted that the student expressed an understanding of how, when, and why to make those measurements, then it was determined that the student held a full understanding of data collection.

Understanding is utilized when discussing a student's grasp of the various elements which make up a premise. For example, in the previous scenario the student demonstrated a full understanding of data collection. However, in many cases after passages were coded, interpretation of the transcript revealed that students did not hold full understandings. In these cases, students only held partial or incomplete understandings of the element of the premise.

When describing a student's grasp of the entire premise, the term conception is used. For example, a student may have a full understanding of data collection, but only a partial understanding of communication. In this case, this student's conception
of that entire premise is only partial or incomplete. A student must have a full understanding of all of the elements which make up a premise in order for that student to have a fully formed conception of the premise.

The reliability of this coding and interpretation was checked by comparing the codes and subsequent interpretation from randomly selected student interviews by several different coders (Bishop & Anderson, 1990). Any discrepancies in the coding or interpretation of student transcripts were discussed among the four coders, which included a science educator at the university level, a secondary school science teacher, a scientist specializing in environmental research, and a doctoral candidate in education utilizing qualitative methodologies, including formal interviewing, in her own research. Approximately one-half of the transcripts were read by the additional coders. Any discrepancies in the coding or interpretation was discussed until an agreement was reached. In only a few instances complete agreement was not reached, and those passages in the transcripts were discarded.

Once data were coded and interpreted, emerging patterns of each students' conceptions of the nature of science were identified and tracked for the entire school year. Patterns were also noted and tracked for each project-based class. These various snapshots taken together over the course of the year allowed me to determine if any conceptual change occurred for each student regarding his or her understanding of the nature of science. The result of this extensive participant observation and interviewing process was rich description, vignettes, and narratives of student understandings of the nature of science, and these appear in the next chapters. Finally, interpretation of the
descriptive narratives is provided in the final chapter in order to explain any potential reasons for changes in the conceptual development of students' understandings as specifically related to the project-based nature of each class.

**Getting It Right: Managing Bias**

Qualitative research is often criticized as being subjective and perhaps biased. Managing one's own biases and subjectivity in all research is essential to produce an accurate, well balanced effort. Biases can creep into the research process from the initial stages of formulating research questions to the final sentences of one's interpretation during the writing stage. Peshkin (1988) writes:

> The point I argue here is that researchers, notwithstanding their use of quantitative or qualitative methods, their research problem, or their reputation for personal integrity, should systematically identify their subjectivity throughout the course of their research. (p. 17)

He makes a point of stating that we as researchers should identify our subjectivity regardless of who we are, what research methods we are using, or what question we are investigating. He believes that our subjectivity can unfairly filter or misconstrue the way we collect and subsequently report on our data.

In order to manage our own biases we should attempt to eliminate them as best as we can, or at least make our readers aware of them. By making our readers aware of our biases, we can provide them with an honest framework by which they may read and interpret our description and analysis. For example, one's own beliefs about the nature of science certainly will have an impact on a study such as this. However, because the model of the nature of science developed for this study represents my own
beliefs and was explicitly reported as such, readers are cognizant of them.

Erickson (1984) writes, "The desirable goal is not the impossible one of disembodied objectivity...but of clarity in communicating point of view...both to myself and to my audience" (p. 60). For this reason, I include the following subsection regarding my previous experiences with each project-based setting.

The Researcher

In this section, I briefly discuss my previous connections, and perhaps biases, regarding Project Seafarer at Woodland High and the Forest Watch project at Valley High, both of which I had input into developing. My involvement with the Forest Watch project goes back nine years, when I helped develop an outreach program on which the current project is based. This included the construction of curricular materials as well as the participation in professional development workshops for teachers interested in joining the program. My current involvement in the ongoing program includes support from a National Science Foundation grant which is designed to help facilitate the expansion of this program beyond the New England region. Throughout this research I continue to develop materials, train teachers, and coordinate an evaluation effort designed to provide feedback to the program's sponsors. The current study will serve as one component of that evaluation. At the time of this writing, the pilot study has been accepted for publication, and addresses various aspects of the program's design and goals (Moss, Abrams, & Robb Kull, in press). I had no previous contact with personnel at Valley High with the exception of Daria, the
teacher, with whom I have interacted with regarding Forest Watch prior to the onset of this study.

My previous experiences with Woodland High were much more recent than at Valley. During the spring of 1995, immediately prior to the onset of the pilot study later that fall, I was contacted by personnel at Woodland High regarding my participation in a collaborative grant proposal designed to bring technology into the schools. The proposal was accepted and Project Seafarer was born. I had minimal involvement in the development of this project, since much of the philosophical and logistical ground work was completed by the teachers and administrators at Woodland prior to my initial contact.

I have often discussed my role as researcher with the teachers, and in both cases they welcomed a critical eye in their classroom. However, at no time during the study were the emerging findings discussed with teachers or participants. As for myself, I feel confident that I can continue to meet my obligations which pre-date this research and still provide accurate descriptive accounts pertaining to each project-based class.

Limitations of the Research

With the choice of a qualitative research strategy exists the potential problem of a small sample size. It is not feasible to regularly visit a large number of classes and elicit rich descriptions from large numbers of students. For this study, the richness of the descriptive data remains the primary goal, and as such, sample sizes needed to
remain "small." When considering the generalizability of results, educational researchers have questioned what can be learned from qualitative research which often makes use of "small samples" and "no statistics." I will borrow the simple but insightful words of Wolcott (1988), "All we can!" (p. 16)

Additionally, when making use of qualitative methodologies one must consider the effect of extended questioning about the nature of science on students' beliefs in this area. Did the several hours of formal questioning over the course of the year influence students' conceptions? Perhaps the appropriate question should center around how extended interaction with students affected their beliefs, because it most likely did in some way. However, through the pilot study the core line of questioning was developed to help minimize that effect. Scientific vocabulary was rarely utilized in questions unless introduced by participants, and every attempt was made to not lead students to respond in certain ways. Ultimately, one must accept that this research design fostered a change in student beliefs as the year progressed, and although hopefully minimal, it is impossible to determine the exact extent of the effect.

Finally, recent research has documented the importance of teacher beliefs regarding the nature of science as those beliefs ultimately relate to student beliefs via classroom practice (Abd-El-Khalick et al., 1997; Brickhouse, 1990). Understanding teacher beliefs can potentially help in the understanding of where and how students develop their ideas. Although the current study does not explicitly probe for teacher beliefs, uncovering their beliefs might provide greater insight into student beliefs. Future work on teacher and student beliefs and preservice teacher preparation...
regarding the nature of science will be discussed in the final chapter.

**Ethical Issues**

Much has been written about qualitative educational research and ethical issues (Deyhle, Hess, LeCompte, 1992; Phtiaka, 1994). Deyhle et al. (1992) note that few researchers state that their purpose for being in schools is to do ethical research, but people conducting research in schools often find they are forced to make ethical decisions. By simply initiating a researcher/participant relationship one has begun to make ethical decisions. To avoid an exploitative relationship, the interactions among all members involved in the current study were thought of as reciprocal in nature. There were times when data collection had to be suspended due to a personal problem of the participant or a particularly busy time at school. Directed journal entries were foregone in order to not apply undue pressure on the participants. In addition, safeguards such as pseudonyms were used to protect the schools' and each individual participant's identity. Maintaining confidentiality was a priority.

For many qualitative studies, participant observation is the cornerstone of data collection, but when one enters a classroom setting where should one focus one's attention? Boostrom (1994) writes, "Even for experienced investigators, the problem of choosing what to look at can be daunting" (p. 51). I have experienced this dilemma first hand, but have found that honesty, flexibility, and common sense have served me well. When interacting with students at both Woodland and Valley, I was honest with them regarding my research agenda, telling them I was interested in what they thought
about science, and allowed the students themselves to help guide what I focused on or to whom I spoke. I tried not to be the mysterious researcher from the "big university" who came to observe the class as a scientist might observe rats in a maze. I was aware that these were people who had feelings, good and bad days, and their own agenda in terms of what they needed to do. I treated all participants with the respect they deserved.
PREFACE TO THE RESULTS AND DISCUSSION CHAPTERS

The focus of this study was to uncover and describe precollege students' conceptions of the nature of science as they changed during the year in project-based classrooms. It was also important to explore how participation in year-long project-based learning environments may have affected the students' understandings of both scientific knowledge and the scientific enterprise. In order to accomplish this the results and discussion are reported in three chapters. Chapter IV describes the results from Woodland High School. Chapter V describes the results from Valley High School. These chapters include sections on the school and classroom setting, the project-based philosophy and curriculum design of each class, a typical day, a section on each student, and a summary of each chapter which discusses major themes or points from each research site. Finally, Chapter VI discusses the conclusions and implications of this study for both research sites.

Throughout these chapters, transcripts from student interviews are used as part of the text. In all of these transcribed passages, the following notations are used:

D: Refers to myself as researcher.

... Indicates a break in conversation.

( ) Indicates a word was inserted for clarification purposes.

[pause] Refers to a long pause in participant dialogue.

These passages are indented and single-spaced to distinguish them from the rest of the text.
The term *understanding* is utilized when discussing a participant's grasp of the various elements which make up a premise. When describing a participant's grasp of the entire premise, the term *conception* is used. A participant must have a full understanding of all of the elements which make up a premise in order for that participant to have a fully formed conception of the entire premise.
CHAPTER IV

WOODLAND HIGH SCHOOL

The Setting

Woodland High School is a semi-rural New England public school which serves approximately 600 students, grades 9 - 12. By many accounts, Woodland would be considered a traditional school, perhaps even a "typical" school. As one wanders through the locker-lined halls of Woodland, one can peer into classes and observe a typical range of teaching practices, including lecturing and some small group work. As is characteristic of many high schools, some students seem engaged and interested while others, resting their heads upon the desk tops, seem to be uninterested and uninvolved in the classroom happenings.

When I first arrived at Woodland, I perceived that both teachers and students thought poorly of their school. I approached several teachers regarding this issue after several weeks of participant observation, and they laughed and described this as the "Woodland sucks" phenomena. They explained that students and parents believed that the quality of education at Woodland was very poor. Although the teachers themselves felt that there were many good things happening at this school, it was hard to overcome this deeply entrenched image and as a result it affected the morale of much of the faculty.

The facilities themselves, although not extravagant, seemed more than adequate to serve the current student population. The average sized library held several dozen computers for student use, but perhaps more importantly, had an engaged and active
librarian overseeing the daily operations. Woodshops, art rooms, and science labs contained the basic space and equipment needed to operate effectively. Perhaps one element leading to poor student attitudes about their school was that there was very little extra to go around. Facilities at Woodland were adequate, average, acceptable, but rarely exceptional, outstanding, or "state-of-the-art." Although there were computers in the library, technology was an area in which the school strongly wished to make some gains in terms of both the quality and quantity of technology available for use throughout the school. Parents, teachers, and administrators supported advances in all areas of technology.

Toward this end, the School Board had recently created a new position in the district titled Director of Technology. This qualified individual was in place approximately one year prior to my involvement with this school. The Director had begun, within the confines of a limited budget, to revise the technology curriculum while at the same time upgrading the school's computers. It was clear that additional funding would be required to meet the goals outlined for advancements in technology.

Woodland, in cooperation with the University of New Hampshire, applied for and received a substantial private grant which provided funding for computers and teacher training in technology to support the proposed Project Seafarer curriculum. From the outset, this project was viewed as an experimental or pilot curriculum within this school community, and would serve to explore "a new kind of learning" designed to improve both the quality of education and image of Woodland.
Project Seafarer Environment

The curriculum and facilities of Project Seafarer were mostly isolated from the rest of the school. The technology room, which was at the heart of this class, was located in the back of the school set away from most other areas. The room, approximately 25 by 40 feet, was lined with about 20 computers and associated peripherals including two scanners, a video setup, and several printers. During the first several months of the pilot study year only several older computers were present, but by November 1995 the room housed state-of-the-art technology. It took the balance of the first year to fully integrate this technology into the classroom. However, the newer technology was in place and up and running, including internet and electronic communication capabilities, for the first day of school during this second-year study. It represented Woodland's achievement in beginning to secure and provide "exceptional" facilities for their students.

In the center of the room stood two tables at which students sat around sharing ideas and completing work. This was an active classroom. It was utilized by other computer classes earlier in the day, but for the last two periods of each day it belonged to Project Seafarer and was buzzing with activity related to that class. The walls were filled with titles of student projects, as well as posters and pictures dealing with the whaling theme which guided much of the work in this class. The white board located in the front of the room often contained daily or weekly schedules as well as a checklist of what needed to be completed in order to finish the boat by the end of the 1996-97 school year. As a researcher, I found it quite easy to circulate the room and
interact with students as they independently worked on their projects.

Directly below this classroom was the wood shop, which contained work benches, table saws, and other wood-working equipment. It is in this wood shop that students created the five oars, center board, and mast needed to outfit the boat being built out in the boat shop.

A short walk out the back door of the wood shop was a small three bay garage-like structure which contained maintenance and custodial equipment in one bay and the boat shop in the remaining two. Several benches and places for tools lined the walls, but clearly the most prominent structure was the boat itself. A 28 foot 19th century whaleboat was hard to miss. It was not a whaling ship, but a boat which might be carried with four or five others on a whaling ship for a several month excursion. Early on in this second year of the study, the boat began as a solid oak keel on the floor, but slowly the molds which shaped the boat, the planks which overlaid the molds, and all other parts of the boat took shape. Eventually, an impressive and quite beautiful structure filled this moderate space.

Students, teachers, and preservice interns split their time between these three environments for the duration of Project Seafarer. The curriculum and underlying philosophy which drove this class will be discussed in the next section.

**Project-based Philosophy and Curriculum Design**

Woodland High School described Project Seafarer as "a model for student-centered learning using computer technology" in their literature on this new class. The
The following nine points were drafted by Woodland as the underlying premises of the project-based class:

1. The class is composed of a heterogenous group of juniors and seniors.
2. Students are expected to reach for exemplary standards that describe world class learners in their subject areas.
3. High school students are engaged in building an authentic 19th century whaleboat.
4. The whaleboat serves as a theme for learning in other academic areas.
5. Students are expected to develop essential questions about whaling or issues related to their subject area.
6. Each student is assigned a teacher-coach who monitors individual student learning through weekly meetings.
7. Preservice teaching interns from the University of New Hampshire assist students with daily learning.
8. Research in pursuit of answers is done with computer technology as well as print materials.
9. Assessment is accomplished through multimedia presentations shown before an assessment panel consisting of teachers, interns, and other students.

Project Seafarer was designed to be a new kind of learning, and certainly a new kind of teaching, for this traditional high school. During the very first class period of the pilot year, Jack, the lead teacher for the project stated, "Last year we were the bottom
of the barrel, now we are state-of-the-art." By the second year of the study, at least regarding technology, they were. However, technology played only one part in this project-based curriculum.

Whaling or whaleboats is an odd theme on which to base an entire curriculum, however Jack, the lead teacher, built boats as a hobby outside of school. One day several years ago in which teachers were encouraged to share their interests with students, Jack brought in a small sailboat that he had recently built. Both teachers and students were intrigued with the idea of boat building, and the seed which became Project Seafarer was sowed. Jack knew first hand the creativity, hard work, and problem solving that went into building a boat from scratch, and thought it would be an excellent way to involve students in something beyond the memorization of facts so common to many classes.

Not unlike many teachers that have been in the classroom for 20 years, Jack was ready for a change. In his case, that change became the challenge of incorporating many of the ideas and teaching strategies that he experimented with over the years into an entirely new class. He received strong support from the administration in the Woodland district, and a core of teachers signed up to serve as coaches. At the same time, the University of New Hampshire was looking to cluster their preservice interns, who are in the classrooms for an entire academic year, into supportive environments. From the outset, creating this project-based class broke new ground and tested the traditional "rules" at Woodland. Typically one teacher was assigned to approximately 25 students, but two full-time lead teachers, six preservice interns, and approximately
10 mentor teachers worked with students in various capacities in this class.

The selection of junior and senior level students for participation in the class provides insight into the Seafarer philosophy. For the first year, there were over 80 student applications for participation in the class which was limited to 18 slots. Eighteen students were the maximum the teachers felt they could adequately serve based on the school's limited resources, such as the number of available computers. As a result, student selection criteria were developed to make the selection process both fair and efficient. A balance of students was selected from all levels within this tracked high school by writing an essay and requesting references from teachers. Students accepted into the program showed evidence, through their essay and/or recommendations, of: their ability to work in a team atmosphere; having no record of serious disciplinary problems; their ability to communicate well with peers and adults; a desire to work diligently; and their willingness to try a new approach to learning. In addition to selecting students from all academic levels from within the school, a gender balance was sought. Prior to the final selection, students were interviewed by the two lead teachers, Jack and Emerson.

The class developed a reputation during its first year of implementation of being very difficult and requiring a lot of time, therefore the second year was not as competitive even though the selection process was similar, because fewer students applied. It became clear from the selection criteria for both years that students were going to have to be motivated and be willing and able to demonstrate their own learning and growth throughout the entire project-based class. As outlined in the
underlying premises for Seafarer, this class was designed to be student centered and
students were expected to take partial responsibility for their own learning.

Once students applied and were accepted into the class, they selected an area
for academic study for each semester. Students could choose from courses in the
sciences such as environmental science, anatomy, or independent study science, or
non-science courses such as journalism, social studies, independent study art, pottery,
creative writing, English, literature, drafting, or photography.

During the second year of the study, the class met for two full periods each
day. Students would spend half those periods working on individual projects centered
around the whaling theme and grounded in their chosen academic areas, and the other
half of their time working in teams on the boat. They received a computer credit one
semester and an industrial arts credit the other semester. Most students selected one
academic credit for one semester and a different academic credit for the second
semester. It is important to note that all four credits (two academic, one computer, and
one industrial arts) that students received for a full year's enrollment in Project
Seafarer counted the same toward graduation as if they had enrolled in the designated
traditional classes.

Once their area of study was defined, students were assigned a mentor teacher
from the participating faculty along with two preservice interns. Mentor teachers
would meet with the students on approximately a weekly basis and guide the direction
of each project. Students were required to generate contracts for each project to outline
the goals of their proposed work. Since interns had daily contact with the students they
often helped students develop these contracts. During the weekly meeting with the mentor teacher, the contract would be reviewed and approved by all parties. In many cases this interactive process took a couple of weeks.

Probably the most important element of the contract, along with a time line, was the essential question for the project. As will be discussed later, the notion of "essential questions" was poorly understood by many students. Regardless, it was these questions which guided their projects. Answers to essential questions were sought through research in the library, speaking with "experts" in a given field, or making use of the internet to download information related to the project. This phase of the project could last several days to many weeks. Once the information for a project was gathered, students created the "product" of their project, which was in most cases a multimedia presentation. Generating the presentation lasted a week or two, sometimes longer. During this period "critical friends" could be used by each student to refine the presentation. Critical friends were student peers in the class who were formally solicited by the student to provide both positive and critical feedback regarding the multimedia work prior to the final presentation.

The presentation of projects was the primary means for assessment in Project Seafarer. Students were required to present two or three projects per quarter, or a total of 8-12 projects per year (two quarters per semester). When students inquired on the first day of class about assessment, specifically regarding how they were to be graded, Jack responded, "You will tell us what you know." Students accomplished this by presenting their project to a panel of teachers, interns, and students which included
their mentor teacher, interns, and critical friends. Additional teachers or interns often sat in on presentations, bringing the panel up to six or so people. Students were assessed using the "Project Seafarer Grading Guide" either as quality, above average, average, or no credit in 12 different areas, including: clear statement of essential question, clear answer given to essential question, appropriate use of technology, appropriate use of research sources, pushed limits of knowledge and abilities, as well as others (see Appendix B). This assessment was "converted" into a numerical grade for each quarter and semester by the mentor teacher and interns. In many cases, students had input in this process, although the final decision rested with the mentor.

In addition, students were also evaluated on their growth toward understanding the "standards of world class learners." For example, in science, a world class learner is one who can:

- Use knowledge as a vehicle to do good for humankind.
- See how science relates to other disciplines and all aspects of the world.
- Use curiosity and perseverance as tools in the quest for scientific knowledge.
- See the complex in simple terms in order to communicate ideas and knowledge to people of any ability.
- Interpret data objectively.
- Find novel and/or creative methods for solving problems.

Students' efforts and success toward understanding these ideas will be discussed later. Standards for world class learners in math, history, art, craftsmanship, and English are presented in Appendix C.
If students were unhappy with their grade on any given project they could redo that project, which entailed presenting the project again in an attempt to receive a higher grade. However, due to the pace of this class and the responsibility of building the whaleboat in addition to their academic work, this option was rarely taken.

Work on the boat was designed to be as important as work toward academic credits. Unlike individual academic projects, students were expected to work cooperatively on various aspects of the boat. To facilitate the construction of the boat, students were allowed to select teams, known as crews, in which they worked on lofting (drafting) the boat to full scale, laying the keel, building the molds in which the planks were bent around, planking the boat, or building the oars, mast, centerboard, and rudder. Since mentor teachers received no class release time for participation in Project Seafarer they rarely worked on the boat itself, however interns were seen working side by side with students every day. Assessment in this area was based on the actual progress of the boat and the students' willingness to learn new tools or skills associated with the boat's construction. Both lead teachers, Jack and Emerson, were responsible for coordinating this aspect of the class.

Clearly underlying this entire class was a philosophy supporting a student centered approach to learning. Students were responsible for choosing and completing projects along with the actual construction of the boat. Jack described the philosophy of Project Seafarer as, "Let the student's go, and they will go to wonderful places." He also described this class as "setting the stage" for learning. Jack felt that by providing an environment for students to experience success, and failure, was one of the most
important things he could do to facilitate learning.

Project Seafarer was a different experience for each student depending on their academic credit and boat crew, and as a result they went to different "places" either through their successes or failures. They had tremendous autonomy and choice regarding their daily work. Students truly made this class what it was. Almost every day brought new challenges to the class. A "typical day" in Project Seafarer, including many day to day activities for students, is described in the next section.

A Typical Day

Although it would be difficult to convey the essence of Project Seafarer by describing one typical day, there are elements of various days or weeks that can be described which will provide insight into the daily operation of the class. I would arrive at Woodland mid-day during the school-wide lunch period to find several students in the classroom eating their lunch and working on their projects. Jack would be at his computer located in the front of the room trouble shooting a technical problem, corresponding to the mentor teachers, or working on some problem regarding the construction of the boat. Both the computers and the boat required endless hours of attention by Jack to keep the class running smoothly.

Since my focus was examining student conceptions of the nature of science, I selected students who were working on academic credits in the various science areas. I would often sit beside one student during this pre-class time and inquire about the project that he or she was working on. It was an excellent time to discuss how the
project was going, if they were finding answers to their essential questions, or what was "scientific" about the project itself. I had excellent rapport with most students and they freely discussed their work and filled me in on what had happened in class since I was last there.

Once the bell sounded, the class came alive with students and interns flocking to the room. Discussions about presentation dates and other scheduling issues, computer problems, boat problems, and any other topic regarding this class took place as everyone filed into class. There was always an energy that unfolded when everyone was in the room.

Approximately one half of a class period was set aside on Mondays for the weekly planning meeting and on Fridays for the walk through meeting. During the planning meeting, which was led by a different student each week, the class would discuss which periods during the week would be reserved for academic work, and which for boat building. At the walk through meetings at the end of each week the various boat building crews brought each other up to date on the progress of their work. Although the weekly schedule remained fairly constant, there were times in which certain students requested either more boat or academic time. Any changes were usually accommodated at the planning meeting once everyone in the class had a chance to provide their input.

Approximately midway through the second year it became clear to Jack that the boat was not going to be finished unless more time was spent working on it. During one class session in December he announced, "We've got this thing to build,
and it's going to take extra time." As a result, boat building hours after school and on Saturdays were scheduled. As will be discussed later, several students resented this extra boat time, and felt more time should be spent on academics.

I spent most of my time at Woodland in the computer classroom speaking with students, or I met with students in the library to inquire about their research. During a typical academic period students sat in front of computers and worked on their projects. The diversity of projects that students worked on was tremendous. Essential questions included: How have whales inspired us culturally over time? What attracts people to the ocean? and How do computers assist in exploring different techniques of drawing boats? Science related essential questions included: What is the structure and life history of the shark? How do volcanic events effect the ocean and ocean life? How do oil spills effect the ecosystem of the ocean? and How is modern day whaling effecting the whale population?

Students made use of the abundant technology available to them. They explored the internet for information, created multimedia presentations using Hyperstudio and Power Point software, scanned in documents and pictures, captured video segments off of the VCR, made use of word processing software, and developed their own graphics and pictures for inclusion into their projects. Although students interacted with each other at the center tables as they made their way throughout the classroom, most students worked independently on their projects when at the computers. Preservice interns were ever present in this room to help students with any questions that arose.
During a presentation a group of teachers, interns, and students would form a semi-circle around a student who sat facing them while next to a computer. There was usually a few minutes of "shooshing" and "quite please" prior to a presentation as other students did not leave the classroom setting, but continued to work on their own projects at other computers in the class during formal presentations. Students referred to presenting as "on the hot seat." Except for the students sitting on the panel and actually viewing the presentation underway, other students seemed to look anywhere else but at the ongoing presentation.

Although a few presentations were designed to be "stand alone" and essentially run without any verbal input from the student, most presentations were a combination of the student discussing his or her work while showing various pictures or bits of information on the computer screen. Although presentation times were quite variable, they lasted approximately 20 minutes including time for questions. The panel observing the presentation would jot down notes, perhaps ask questions, but more often than not would sit quietly and appear genuinely interested. Occasionally there would be an "ohhh" or "ahhh" at a particularly nice graphic.

Other than listening in on presentations, I would inquire about various aspects of student projects throughout the several hours I was in class. Although most of the time I would focus on the students selected for formal interviewing, I didn't want to seem like I was "picking on them" all of the time, and would occasionally work with other students in the class. On many occasions, I would not want to interrupt students for too long because they always seemed pressed for time to complete their work.
Students fell into one of two categories during any particular day: either extremely busy, focused, and working hard or procrastinating, possibly frustrated, and accomplishing very little. The next section which will describe each student in terms of their understandings of the nature of science will also address their unique experiences in this class over the entire school year.

Meet the Students

Ben

Being an outspoken, confident young man, Ben always enjoyed speaking with me regarding his experiences in Project Seafarer. He was a college bound senior at Woodland who participated in numerous school clubs and activities, including playing the lead in the school play. He achieved high grades throughout all of high school, and seemed to enjoy all aspects of school. Prior to his senior year he had enrolled in all the standard science courses at Woodland, including Introduction to Secondary Science (ISS), an integrated physical science and life science course all ninth grade students were required to have, biology in tenth grade, and chemistry in eleventh grade. During his last year in school he enrolled in the physics course in addition to Project Seafarer in which he took a social studies credit the first semester and a math credit the second semester. Although he enjoyed social studies, he also liked science and math and his long term goal was to become an aeronautical engineer and design rockets for space travel.

He completed four projects throughout the year, two each semester. The
question for his first social studies project was, "How have whales inspired us
culturally over time?" and his second question read, "Compared to the sea chanteys of
the 1800's and how they reflect their culture, how does my sea chantey reflect
Seafarer?" His two math questions which guided his projects for the second semester
were, "Why are the whaleboat's oars in such an odd configuration?" and "How was
celestial navigation used during a typical whaling voyage?"

As with all participants in this study, both at Woodland and Valley, I will
describe their conceptions of the nature of science using the model presented earlier to
guide that discussion, and as a framework to judge if their conceptions are fully
formed. The first premise which reads "The universe is open to human description,
classification, and understanding through scientific exploration," was perhaps the most
difficult one to examine. The reason for this being that most participants felt that this
premise was "a given." The following dialogue with Ben is revealing:

D: Is there a common goal to all of science?
Ben: Learning. Discovering things about the universe.
D: And do you think science can do that?
Ben: Definitely. It's done that. And it is doing that today constantly.
D: Do you think we'll be able to discover everything about the universe?
Ben: Everything that ever has and ever will exist? There's a lot to the
universe.
D: Does science have the capacity to discover all of that? Whether we can
or ever will or not, let's say that's a different question.
Ben: I think it does, yes.
D: And then the second part of that, do you think we ever will?
Ben: It depends. I think that we have the ability to do it and the capacity to
do it, but then again there are certain things that people either don't
want to know or don't need to know because they already know about it
in a different idea. Like say you know a lot about earth and you learn
about this other planet, you might learn about the culture and things but
you don't need to learn about the minerals and everything on that planet
because you already know about it.
This dialogue took place during the fourth formal interview which was in March, and there is no evidence that Ben's beliefs regarding this premise changed over the year. For Ben, like all participants, scientific exploration was the means in which knowledge about the universe was generated. In fact, Ben and others felt this was the single most important thing science could do. "Finding out how things work" and "understanding about the world" were common phrases that students used when discussing the purpose of science.

Ben nicely articulated the AAAS (1989) notion which states that the universe is a single system in which the same rules apply everywhere, when he discussed that when you know something about one planet, that knowledge will transfer or apply to other planets you may be studying. In addition, he specifically stated that humans have the capacity or the potential to learn many things about the universe through scientific exploration. He had a complete understanding that the universe is open to human description and classification through scientific exploration, but only a partially conceived understanding about ways in which human beings can come to know our universe.

Like many students, Ben believed that science is the only way of coming to know the universe. One explanation for this shortcoming in student beliefs is what I have come to think of as the "everything is science" phenomena. There may be many reasons for this misconception, but in part I believe this phenomena may have come about through science instruction in which science teachers attempt to explain the relevancy of science to a student's life when answering the question "Why do we have
to learn this?" In fact, the standards for world class learners for Project Seafarer even reads, "See how science relates to other disciplines and all aspects of the world." Note "all aspects of the world." Students may have taken the notion that science can be seen in much of our daily lives, and extended it to believe that everything is science. Students in this study have often articulated that "there is a science to everything," when what they most likely mean is that there may be a systematic way of doing something or an organization to many things. For example, Ben commented that he experienced a lot of science on a school trip to Italy. When I asked him about the science on that trip, he responded:

Just learning about all the different things...you know, in order to get lunch what you do is you have to pay first and then you bring the ticket up to the counter and tell them what you want. It's not like McDonalds that way.

There is an organized system to purchasing lunch as well as organization in science, but here Ben is not referring to scientific inquiry or knowledge. I believe he is merely mistaking the organized nature of science for science itself.

Other areas of inquiry besides science are also organized and systematic. Philosophical inquiry, historical inquiry, and even spiritual inquiry are not necessarily scientific inquiry, although there certainly may be some overlap, but they are alternatives to scientific ways of generating knowledge about our universe. If Ben believed there was a "science" to everything, then perhaps it is not surprising that he did not consider other ways of coming to know our universe than a scientific one. Throughout the duration of this study he believed that "science" was the sole means in which humans came to discover things about our universe. As a result of his lack of
understanding of this aspect of the premise, Ben only had a partially developed conception of the first premise.

The second premise of the model states, "This scientific exploration attempts to explain and predict phenomena, compare theories, check on previous results, and generate new questions." In essence, this second premise serves as a definition of science. Ben was asked to define science numerous times over the course of the year, and during the first interview our conversation went as follows:

D: So how would you define science?
Ben: Let's see. Science is sort of the, let's see how can I put this into words? It's like the physical way of trying to answer a question. It's sort of like the physical version of philosophy. It's like doing specific research and doing experiments in order to answer a specific question or prove or disprove a hypothesis...

D: What do you mean by an experiment?
Ben: Any sort of a reaction or observation that you can make in controlled circumstances to prove or disprove a theory.

During our third interview, which took place in January, he stated, "Define science, huh? Well, science is the process of I guess discovering things about nature and life.... I think it's just the process of discovery I guess." For the fifth interview he defined science as, "...the process by which people go about learning and finding information." Finally, for the last interview of the year, he similarly asserted, "Well, I would say science is the process of learning and understanding the world and how it works." Throughout the year he explained that science was answering a question, doing research and experiments to test hypotheses, proving or disproving theories, discovery, finding information, and learning how the world works. In each case he thought of science as a process. He often made use of the phrase "how things work"
when discussing science, and in the last formal interview even stated that science will "try to figure out...how things might be in the future" which addressed the predictive nature of the scientific enterprise.

Although I probed for his beliefs about scientists checking on previous results and generating new questions for study, they were absent from Ben's explanations. Because of the lack of these elements in his descriptions of science, his conception of the second premise was incomplete.

The third premise of the model of the nature of science states, "Logic, imagination, curiosity, and serendipity contribute to scientific exploration." Although Ben discussed the importance of curiosity in science as early as the first interview, it was in the third interview that he stated:

The key aspect to (science) is curiosity. If you don't care that ice is made of water, then there is no point in doing the experiment. Without (curiosity) science wouldn't have any use.

In addition, during the fifth interview he described scientists as needing to be inquisitive and creative thinkers. Finally, during the last interview he commented:

The real important thing about science is just the curiosity, the drive to want to understand how things are and how they work. Without that curiosity then science to someone would probably be very boring.

As you can see Ben expressed quite clearly at several points throughout the year the importance of curiosity in doing science. It is important to note that he not only felt that curiosity contributed to science, but was fundamental to science itself. He also mentioned creativity and imagination as being important traits for scientists and subsequently the process of science. In addition, like other students, he felt intelligence
or logic were important, and contributed to the process of science. He held these fully formed beliefs throughout the entire school year.

The only aspect of this premise that he did not mention at any point over the course of the year was serendipity. Serendipity is commonly defined as "finding without seeking," but is more commonly thought of as "luck." I included this notion in this premise based on two considerations. The primary reason for including this idea was based on my own experiences conducting scientific research, where on more than one occasion I felt serendipity along with a prepared mind to take advantage of the fortuitous events contributed greatly to my overall research efforts. For example, a forest decline study in the northeastern U.S. (Moss, Rock, & Bogle, in press) was influenced by the late season visitation of a television crew interested in documenting the work. If it were not for the film crew I would have never visited the field site and been able to document the severe forest damage which occurred following the final planned sample collection date. In addition, I included this notion based on what I know of the history of science. In many instances throughout recorded history luck has played a role in scientific discovery, such as the development of antibiotics.

Although I am not familiar with Ben's knowledge of the history of science, I do know that he has limited exposure to conducting scientific research, therefore I was not surprised to see serendipity not surface in our conversations. His overall conception of this premise was incomplete because of his lack of understanding of this aspect of the model.

The fourth premise states, "Scientific activity is a social activity conducted by
individuals who are influenced by both cultural and personal factors." To partially examine this question I asked the participants, including Ben, "If two scientists did the exact same research, would they get the same results?" Throughout the several interviews in which I posed this question, in each case Ben commented on the external factors of an experiment, such as temperature, to conclude that the results would be similar, but not exactly the same. At no point did he discuss any personal factors which may influence science such as biases or previous experiences of the researcher which may effect the conclusions. He thought of scientists as objective, impartial beings.

However, he did have an understanding of the social or cultural factors which may influence the scientific enterprise. Regarding where he thought ideas came from for projects that scientists worked on, he stated:

If a scientist works for a company then whoever runs the company or if the company works for someone, whoever that company works for decides what that scientist will do. So if you work for a company that builds weapons then you're going to be a scientist about making weapons.

Ben's conception of this premise was just partially formed because did not describe science as being influenced by personal factors, only cultural ones. His beliefs in these areas remained consistent over the course of the year.

The final premise describing the nature of the scientific enterprise outlines what is commonly known as the scientific method. It states, "Questioning, data collection and analysis, drawing of conclusions, and communication are the major phases which characterize the scientific endeavor." His understandings regarding the various elements of this premise were complete and essentially unchanging over the course of
the year, except for his beliefs on questioning.

Ben, from the very first interview, articulated the importance of questioning in science when he said:

Without questions there wouldn't be science. I mean, without a question or a need to find out why things are the way they are, then there'd be no need for science because that's sort of what science is, to find out why things are the way they are to answer those questions.

Later in that interview, he articulated his first project question which was initially "What has the industry of whaling inspired culturally over time?" but found that question to be too narrow. He essentially produced a list, including scrimshaw, to answer that question. He later re-phrased that question to read "How have whales inspired us culturally over time?" in which he was able to discuss art, literature, and cinematography in a manner in which he could explain the influence of whales and whaling on these areas. In the second interview he discussed how he preferred these broad questions as opposed to narrow ones:

I see something that I am interested in and I like to pursue that further... I sort of like to do a more broad base. That way I don't limit myself as to what I do my research into. First of all I end up learning more and being more interested in what I am doing. Also, I come across more things...

Throughout the course of the year he felt broader questions were preferable to narrow ones because of the freedom it gave him to explore areas that were of interest to him.

After he explained his first project to me, I asked him if he felt that was a scientific question and he responded, "Certainly, because it has an answer that can be determined by saying do some research." During the second interview he also stated that his first project question was a scientific question when he explained:
Ben: Well, if you look at social studies in the form of a science then it could certainly be considered a science question.

D: What do you mean by "in the form of a science"?

Ben: Well, I have heard it referred to it as science. It does basically the same thing...you have people coming up with questions..then they go back and do research and come up with research to prove or refute their hypothesis.

It was not until the final interview of the year that he began to think of scientific questions as being different from non-scientific questions:

D: Do you think there are such things as scientific questions versus non-scientific questions?

Ben: I think so. I think there are some questions which I mean like you wake up in the morning and you say, what am I going to wear today? That's not science, that's more of a decision. You know, any kind of a simple question like that. But scientific questions are more in towards learning, trying to figure out how things are...

Unfortunately, he never quite fully distinguished between these two type of questions. His conceptual change in this area remained incomplete. Although he began to think of non-science questions, or "simple decision" questions, as differing from science questions, he still associated science questions with "research" and "trying to figure out how things are." This is why he still believed his social studies questions to be scientific: he was doing research to try to figure things out. He did not consider the content of the questions as contributing to whether they were scientific. Although social science research attempts to "figure things out," one way it usually differs from science is in the content area it encompasses. His evolving understandings of scientific questions remained only partially formed by the end of the year.

Our conversations only occasionally dealt with the next facets of this premise, data collection and analysis, and drawing of conclusions. During the second interview,
I inquired about data analysis:

D: What is data analysis?
Ben: After you do your research you take all of the data you collected, all of the numbers and observations and draw a conclusion from them. For example, where you do a bunch of experiments and ice melts and you get some measurements where it says that it's 31.6 degrees, and other that are 32.6 degrees. You add them together and get an average, that is an analysis of the number that you have.

D: Do you do any data analysis in you projects?
S: Hmm...in a way yeah. That's sort of what I was referring to as the second part of my research. In the case of the sea chantey's... that is the part where you look at it and ask how it is put together and how it is reflecting their culture. What is it actually saying?

On more than one occasion he referred to these steps as the "second part" of the research process. As will be discussed later, these ideas were not emphasized throughout this project-based class, however, his ideas which met the criteria for a full understanding based on the model developed for this study remained consistent throughout the year.

Ben excelled with regard to the last facet of this premise "communication of results." When I asked him during the third interview what happens after scientists come to a conclusion he explained, "After that, you'd publish your results...you do experiments then you come up with conclusions, then you publish it..." He also explained that is important to present work or share work verbally as well.

Unlike most students who honed their presentation skills over the course of the year, Ben began the year with excellent speaking skills. The challenge for his presentations was to have him rely less on himself as the presenter during a project presentation for assessment, and to have the computer graphics be more effective in communicating ideas. He also liked the teamwork and informal sharing of ideas when
building the boat. He was on the crew which had the primary responsibility of constructing the oars, and commented that over the course of the year he greatly enjoyed working in that team atmosphere. He stated during the last interview that sharing ideas and working in a team was an effective way to solve problems. His understandings were consistent and fully developed, and his experiences with both formal and informal communication were certainly positive throughout the year.

The second part of the model of the nature of science developed for this study dealt with the nature of scientific knowledge. The first premise of this section states, "Scientific knowledge demands evidence and is testable through the scientific enterprise." In our first interview Ben discussed the notion of experimentation and empirical evidence to ensure knowledge is scientific. However, in the second interview he stated, "There are some scientific facts that aren't necessarily proved because they are known to be true. The sun rises in the morning and sets at night..." In the third interview he again emphasized "proof" when discussing knowledge in science. In the fifth interview I also asked about scientific knowledge, and he replied, "Everything we consider to be science has been proven...through experimentation."

His beliefs about scientific knowledge demanding evidence and being testable through the scientific enterprise generally met the criteria for full understandings, although his beliefs in this area did not remain consistent over the course of the year. There is no data to suggest why his beliefs evolved in the second interview, and then back again for the remainder of our conversations. Because of this unexplained fluctuation in his understandings about scientific knowledge demanding evidence, I
believe he only had a partially conceived conception of this premise.

The next premise states, "Scientific knowledge cannot provide complete answers to all questions." His satisfactory beliefs regarding this area remained constant over the course of the year. He believed that some questions, specifically narrowly focused ones, could be answered, but that most scientific questions could not. Generally, he felt scientific knowledge could not provide complete answers to questions.

Ben also had a fully formed conception of the final premise of this model, "Scientific knowledge is tentative, developmental, and subject to revision." Early in the year he discussed Columbus and how people once thought that the world was flat and how that knowledge changed. Later in the year he discussed in general terms how scientific facts could change if "better or different evidence to the contrary" was found. During the fourth interview he discussed the developmental nature of scientific knowledge while providing an example from his physics class:

Right now we are studying gravitational motion and things like that. It started with Newton and his ideas and then Kepler came along and solidified the ideas even more. Others found out the gravitational constant for our galaxy. Einstein came along with relativity and explained how gravity is part of the universe. It starts out with a more basic framework and each person adds something more to the basis of it.

In the fifth interview I asked if older science knowledge becomes outdated and has any use, and he replied, "It's the foundation that everything else is built on...you have to start somewhere." Clearly his conceptions in this area were satisfactory early on in the year, and remained so as the year progressed.

The next sub-section will discuss Ben's opinions of this project-based class and
will be followed by a brief summary of his conceptual understandings regarding the nature of science.

**Conceptions of the Project-based Class** - Ben generally had a very positive experience with *Project Seafarer*, as he did with the rest of high school at Woodland. He liked the opportunity to delve into his own questions through this class. His two social studies questions allowed him to investigate any influence between whales and various aspects of culture, and the math questions fostered his exploration of math, history, and whaling. His math-based question which asked why the oars on the whaleboat were in such an odd configuration (two on one side and three on the other) was ultimately answered not through mathematics, but through historical research which uncovered the number of people a whaleboat could hold. All of his research, in math or social studies, was essentially gathering information and compiling it as opposed to collecting original data. He did not pose questions which necessarily required the collection of "original data" as is often the case in scientific work, therefore this was the most appropriate strategy to provide answers to his questions.

At the end of the year, when I inquired if he had the opportunity to pose questions in any traditional classes, especially the physics class he was also enrolled in, he laughed and stated:

I never thought of it in that sense before, it's completely laid out. You come in sit down, take notes...it's more like here is some information and what do you think about this, and everyone thinks the same thing because they all have the same information.

I also asked which class he felt he could learn more in:
Ben: I don't know, it's hard to say. Myself personally I think I probably learn more in the physics class because of the structure, it more clearly defines a lot of more specific things. It's a bunch of little things that when you put them all together they add up to one big thing. As with Seafarer I have learned a lot, but it isn't all in the same subject area. It's hard to weigh. In physics, I have learned a lot of physics, but in Seafarer I have learned a lot about building a whaleboat, how to use the computers, and doing research and finding an answer to a question. Weighing that out it's hard to say which one I have learned more in.

D: But you feel you have learned in both?

Ben: Oh definitely!

D: Have you enjoyed both equally?

Ben: No, actually I have enjoyed Seafarer much more than physics. There are some learning styles that I liked and others that I really don't like. In physics class is basically the teacher gives you notes and you take notes and that's about it. It's really boring for the most part. Granted there are some interesting demonstrations that the teacher does, but it's not quite as stimulating, you know it doesn't get my mind to think as much as it does in Seafarer. I mean in Seafarer it's a lot more solving problems, you know, I need to figure out how to do this, well how do I do that? Then my brain gets to work more.

As I stated earlier, Ben has typically achieved high grades in school and was college bound. He admitted that he "knew the rules" of traditional classes and did well there. During the first project, in which he investigated what the industry of whaling has inspired culturally over time, he changed his question from a narrow focus to a broad one. This experience was one of the few opportunities in recent years that he thought he might academically "fail." I was not surprised to have him say that he may have learned more in his traditional physics class than in this project-based class because of the greater amount of content covered in the traditional class. However, he certainly learned and experienced quite a lot in Seafarer, as he had the opportunity to explore his own questions, enhance his presentation skills in that already strong area, and work in a team atmosphere on the boat. I'm sure these experiences will serve him well when
next year he attends a well known university which specializes in engineering as he pursues his interest in that area.

Summary - Generally, Ben's conceptions of the nature of science remained mostly consistent over the year. He believed that the universe was open to scientific exploration, although he had a poor understanding regarding science as merely one mode of inquiry. This was underscored by the "everything is science" notion in which he confused the organized, systematic nature of science with science itself. He described science as predictive in nature, comparing theories, and explaining phenomena, but did not discuss science checking on previous results or generating new questions. He also understood the importance of curiosity and logic, if not serendipity, and held a realistic notion of where scientists sometimes get their questions for study. However, he did not fully understand the role personal factors play in the scientific enterprise. His understandings of the phases of the scientific method were fully formed except for questioning. He articulated the importance of questions in science, and by the end of the year explained partial differences between scientific questions and non-scientific questions, although he still felt that if research was involved in answering a question, it was likely scientific.

Regarding the nature of scientific knowledge, since he understood the scientific method so well, it was not surprising he believed that scientific knowledge was generated through those techniques. He also clearly understood the tentative and developmental nature of that knowledge and that it could not provide complete answers to all questions.
Bryan

From the outset of his senior year, Bryan could not wait until graduation so he could be finished with school. He typically achieved low grades at Woodland and did not participate in extra-curricular activities or clubs. As he explained during one formal interview, "Once that bell rings, my mind is just not in school anymore."

During Project Seafarer he procrastinated a great deal of the year, and as a result had difficulty completing projects on time, and sometimes at all. He chose an environmental science credit for the first semester and a journalism credit for the second semester. He explained he would have taken a science credit for both semesters, but needed the credit in English to meet the requirements for graduation. At the beginning of the second semester, he stated, "English isn't my favorite subject...I hate writing. You do what you got to do 'cause I need the credit." With regard to science classes, like Ben, he completed Introduction to Secondary Science in his freshman year, biology in his sophomore year, and chemistry in his junior year. However, unlike Ben, he achieved poor grades in these classes, especially in chemistry which he just managed to pass, and he did not enroll in physics his senior year.

He attempted five projects over the course of the year, with the first two being in environmental science. His first essential question was "Can a captive whale be released into the wild?" and his second was "How do volcanic events affect the ocean and ocean life?" His first journalism question was "How is Seafarer class different from others?" His final two projects were not guided by essential questions as were the first three, however, they were similar to his other journalism project in that he
was required to generate an article that might appear in a newspaper or magazine at the completion of the project. The fourth project described a class field trip to the Boston Museum of Science, and his final project was designed to encourage him to contribute to the publication of The Deadwood, the annual class newsletter which summarized the year in Project Seafarer.

With regard to Bryan's conceptions of the nature of science, as with Ben, I will guide this discussion by making use of the model of the nature of science as a lens by which to focus the description of his beliefs. The first premise, which states "The universe is open to human description, classification, and understanding through scientific exploration" was a difficult premise to examine throughout the study. For Bryan, like other students, it seemed obvious that scientific exploration was the primary means by which the universe is studied. During our third interview, I asked him to finish the sentence, "I think the goal of science is..." and he responded "The whole goal is to solve the problems of the universe." However, he did feel that many problems were difficult if not impossible to examine and solve. Throughout the year, he used the topic of AIDS research as an example of the difficulty humans can face when attempting to solve scientific problems, although when I inquired about what some of those difficulties might be, he did not know.

Like Ben, Bryan suffered from the "everything is science" phenomena. During the second interview, when I asked him what made a particular question scientific, he responded:

Because of the fact that everything is scientific if you think about it. Is a square wheel better than a round wheel? You have to go out and find the information and data and stuff like that. See if it works.
During the third interview he stated, "Everything is science in a way, because you try to figure something out." During the fifth interview I specifically asked Bryan about other ways besides science to find out about things:

D: Are there other ways besides science?
Bryan: Not really, everything is basically science. If you are going to solve something, it's science.

Finally, during the sixth and final formal interview of the year our conversation went as follows:

D: Is there sort of like an essence to science that makes kind of science different from other things? Could you describe that?
Bryan: Well I don't know if it's different because science is everything basically. You might not say this is science but basically it is. It's everywhere.

Clearly, his beliefs in this area remained consistent over the course of the entire year. Bryan considered "solving problems" and "figuring things out" to be solely within the domain of science. Like Ben, his beliefs were fully formed concerning the universe being open to scientific exploration, but these understandings were somewhat undermined by the fact that he felt that science was the only means by which the universe could be explored. He did not think of science as merely one way of inquiring, exploring, and ultimately knowing.

However, unlike Ben, it was not necessarily the organized nature of science which led him to believe that everything could be science, it was more of the applied nature of the scientific enterprise. The fact that he believed that only science solves problems seemed to contribute to his understandings. When comparing science to English at the beginning of the second semester, he described science as "More hands
on. It has a purpose..." That purpose, Bryan felt, was solving problems and gathering information about the universe. His overall conceptions of the first premise were only partially formed because of his belief that "everything is science."

The second premise, "This scientific exploration attempts to explain and predict phenomena, compare theories, check on previous results, and generate new questions," as stated earlier, served as a definition of science. At the beginning of the year, Bryan simply defined science as "The study of life." During the third interview, approximately midway through the year, he also stated science was "the study of [pause] uh [pause] life." During the fifth interview his definition became more vague when he responded that science was "The study of anything, basically."

At no point during the year did he indicate that science examined theories, was predictive in nature, checked on previous results, or generated new questions for scientists to explore. Although his understanding of science changed somewhat over the course of the year, from strictly life science to a broader notion, this broader notion was not an improvement in his beliefs. For example, if he had articulated that science was a study of physical as well as biological phenomena in the universe, then I may conclude that his beliefs evolved toward a more complete understanding. His statement that science is the study of "anything" was too inclusive, indicates that his understanding of science being able to explain phenomena was only partially conceived, and probably represents an "everything is science" perspective. His overall conception of this premise was therefore poorly formed.

With regard to the third premise which states, "Logic, imagination, curiosity,
and serendipity contribute to scientific exploration," Bryan's conception was also not fully formed. During our fifth interview, after I questioned him about characteristics of scientists which might help them conduct their scientific work, his responses were very vague as they were throughout all the interviews. Our dialogue went as follows:

D: Would you say (scientists) are smart generally?
Bryan: Normally about what they are dealing with, yeah.
D: What about creative? Are they artistic?
Bryan: I don't know about artistic, but they definitely have an interest for certain things...
D: What about luck? Is there an element of luck involved?
Bryan: No, there is no luck involved at all.

His conceptions concerning this premise did not change over the course of the year.

Although I believe he thought that logic, or at least intelligence played a role in scientific exploration, he did not indicate that imagination, curiosity, or serendipity contributed at all.

The next premise states, "Scientific activity is a social activity conducted by individuals who are influenced by both cultural and personal factors." During the first interview he indicated that scientists study real world problems which exist, for example:

D: How do scientists know what to investigate?
Bryan: They look for problems, like AIDS, that's a good one, they're out there studying it like to find cures and stuff to it.

Our conversation was similar during the fifth interview:

D: How do they (scientists) know what to explore?
Bryan: Someone has problems, the world has problems and someone needs to solve problems.

He had a basic understanding that science was indeed a social activity usually directed,
and subsequently funded, by various agencies or government groups. In addition, he clearly understood the role societal needs and problems played in the scientific enterprise, and therefore I would describe his understandings as fully formed and unchanging for this aspect of the premise.

With regard to personal factors which may influence the process of science, he felt that scientists themselves could indeed be a factor in the outcome of a study. Our dialogue went as follows:

**D:** If two scientists do the exact same research, will the results be the same?

**Bryan:** They should be, but someone could mess up a little bit and it will be messed up.

**D:** Messed up in what way, do you know?

**Bryan:** Any little step that they have to do, or recording something.

Unlike Ben who believed if results from the exact same research were to differ it would solely be due to external factors in the study, Bryan felt that scientists themselves sometimes could contribute to results which may vary. Although he only stated that scientists could "mess up," at least he understood scientists, as humans, are an integral part of the process of science itself. In addition, he felt external factors could also play a role. He held these understandings over the course of the entire year, and therefore his conception of this whole premise was fully developed and unchanging.

"Questioning, data collection and analysis, drawing of conclusions, and communication are the major phases which characterize the scientific endeavor" is the final premise which deals with the nature of the scientific enterprise. Bryan's conception regarding this overall premise was only partially formed, however his
understandings of most of the aspects of this premise were complete. During the first
interview we discussed science labs from previous years, and our conversation went as
follows:

Bryan: We did a lab. We had to form a hypothesis first.
D: Which is?
Bryan: A logical guess before you do an experiment.
D: A guess of?
Bryan: What will happen. Then you have to do an experiment, then you
have to come to a conclusion. We have to state whether the
conclusion is true or false if...how it went wrong. We have to
record everything, because if you don't record the stuff then
someone can go back again and it won't work.
D: Record what stuff?
Bryan: All the data and information and procedure that you do.

Later in that interview he discussed formulating a conclusion as an important phase of
the scientific enterprise. In addition, during the third interview he stated:

You got to find a problem first, and then you got to figure out a hypothesis
which is a statement which you think might happen. Then you have to do the
experiment itself. Then you have to form a conclusion and state whether the
hypothesis is true or false.

During the fifth interview he described a similar understanding of the scientific
method, this time specifically mentioning publishing one's results:

Well, you got a problem then you have to make up a hypothesis of what you
think will happen. Then you actually have to go through the experiment, record
all the data and publish the information you get and state whether or not it's
true or not.

Although he did not address questioning as part of the scientific endeavor resulting in
an incomplete conception of the premise, he did indicate that one must have a problem
in order to orient or guide one's research.

With his own project-based work in this class, however, he did make use of
questions when completing his work. He described the work on his first project which dealt with releasing whales from captivity into their natural environment as follows:

First I thought of a topic. Then I thought of a question. Then I went to the library and researched it, all of the research and stuff. I pulled all of the information together and answered the question.

Developing an answer to the essential question was important to Bryan in both of the projects which were based on an environmental theme (releasing captive whales and the effect of volcanic activity on ocean life). He felt these were both scientific questions because of the content that the questions encompassed. During the second interview, our conversation went as follows:

D: "What was your essential question for your first project?
Bryan: "Can a captive whale be released into the wild...?"
D: Do you think that was a science question?
Bryan: Yes.
D: What was science about it?
Bryan: It deals with the environment. It had to deal with the oceans too.

He stated throughout the year that questions came easily for him and that he relied on them to guide his projects.

Bryan felt data collection, data analysis, and the drawing of conclusions were closely related, and that scientists made extensive use of them. When we the discussed the role of accuracy in these steps during our first interview, our conversation went as follows:

D: Do you have to be accurate?
Bryan: Yeah, because if you are off by a little bit you can mess up someone else's experiment.
D: What do you mean?
Bryan: Say, you have to weigh a certain chemical. You weigh it and you write .05 when it's .07. It's when they try to do it they might not get the same response so it has to be exact.
Later in the year when discussing accuracy in science his comments were similar, however when dealing with his own project-based work in class he felt accuracy was not an important consideration:

D: What is accuracy?
Bryan: If you take a measurement make sure it is exact. Say it is 73 and a half, don't write 74 or 73.
D: Do you have to be accurate in your projects in any way? Does accuracy play into what you do for these projects?
Bryan: Honestly, not really. It's only for a grade basically...

Because the nature of Bryan's projects, he was not concerned with accuracy. He believed accuracy was only important in making measurements. Since his projects did not involve these aspects of science, and he merely completed his projects for a grade, he believed accuracy was not important.

It was toward the end of the year that he stated that the final step of the scientific enterprise was the most important. During the fifth interview, regarding the communication of results, our dialogue went as follows:

D: So what happens at the end of a scientific study?
Bryan: They publish it and let other people know.
D: Is that an important part of the process?
Bryan: Yeah, it's the most important.
D: Really, why do you think so?
Bryan: Because there is no point if they don't share the information. They're the only one's gaining something out of it. It should be for everybody.

Earlier in the year he stated all the steps were equally as important, however because presentations were emphasized in Seafarer, perhaps his perception changed. Other than his belief about the importance of the communication of results, his understandings of the other steps of the scientific method did not evolve over the course of the year, yet
were fully formed except for questioning.

With regard to the nature of scientific knowledge itself, "Scientific knowledge demands evidence, and is testable through the scientific enterprise" is the first premise which guides the discussion of this aspect of the model. Bryan held a fully formed, unchanging conception regarding this premise over the course of the entire year, believing that scientific knowledge, or as he referred to them "facts," must be proven.

During the third interview he stated his beliefs as follows:

D: Do they have to be proven to be scientific facts?
Bryan: Yes, they have to be proven because if they are not, they're not facts...
D: How do you prove them?
Bryan: Well you find out what the problem is and go do the experiment...

He noted that through an "experiment" one can obtain the evidence needed to generate scientific knowledge.

Bryan's conception of the premise, "Scientific knowledge cannot provide complete answers to all questions" was consistent and complete. He stated that although sometimes scientific knowledge could provide complete answers to questions, that most of the time they could not.

Bryan felt a scientific "fact" would usually remain a fact. Because of this belief, Bryan only held a partially conceived conception concerning the last premise of the model, "Scientific knowledge is tentative, developmental, and subject to revision." However, during the third interview when I asked if scientific knowledge becomes out of date he said "It may," citing that once we believed that the world was flat, but we proved that wrong. There is conflicting data regarding Bryan's understandings of the
tentative nature of knowledge. In most interviews, Bryan believed that once discovered and proven, scientific knowledge was static. There is no data to suggest why his explanation was different during the third interview. Because of this unexplained shift in his understanding of the tentative nature of scientific knowledge, and because he never addressed the developmental aspect of knowledge at all, his conception of this premise could not be considered fully formed.

The next section briefly discusses Bryan's impressions of the project-based class and is followed by a concise summary of his conceptions of the nature of science.

Conceptions of the Project-based Class - At the beginning of the year, Bryan stated that he liked "active" classes, and described the labs in tenth grade as both fun and relevant:

(I like) dealing with active things, like for one lab we had to run in the hall and stuff like that to get our pulse and stuff like that, it wasn't like sitting there and sitting on our butts all day and doing nothing...instead of just biology he teaches it like street biology because it's stuff like we are around all the time.

He referred to "street biology" as an example of topics that were meaningful to him. In defining street biology, he provided an example of a class in which a student returned from being absent because he or she had gone in for an operation and the teacher took that class time to discuss hospital procedures.

Project Seafarer was designed to provide students with the opportunity to choose topics that were also meaningful for them, but Bryan found it difficult to develop projects that he found interesting. He felt somewhat limited by the whaling theme of the class and uninterested in the questions he generated.
At the beginning of the year, he stated that he thought he would learn more in a class such as this because he was uncovering the information himself and developing presentations. He stated, "It's not like I'm going to forget it," when referring to the fact that he had to do the research himself. However, he stated that he found presenting projects difficult, and only liked talking about what he "knew." He said he did not feel comfortable speaking about the projects, indicating that he may have not learned much from this type of work.

He procrastinated and seemed uninterested in many aspects of this class, and by the end of the year became quite critical of the class. He felt the class relied too much on technology, felt there was too much emphasis on building the boat, and generally thought the class required way too much work. He stated, "It's too much (work). I mean they say you've got plenty of time but you really don't." During my observations of class, I noticed many, many times that Bryan sat in the classroom either not engaged in any work, or "playing" on the computer (i.e., adjusting the computers parameters, such as the volume of the sound effects), but not really working toward the completion of any project.

By the end of the year he stated that he found the day to day class boring. He had difficulty finishing his last two projects in which he was supposed to write articles for a journalism credit. Because he didn't turn in any work for these two projects, he did not acquire the final English credit required for graduation. He would need to attend summer school and graduate from Woodland before being allowed to enlist in the armed services. When I last spoke to him at the end of the year he was very down.
on school, even more so than during the rest of the year, and felt that it was holding him back from the rest of his life. He had committed to an eight year enlistment, and was hoping the military was nothing like school.

**Summary** - Although Bryan believed that the universe was open to scientific exploration by humans, he felt "everything was science," and therefore did not understand science as only one way of knowing. He defined science as the "study of life" for most of the year, but toward the end broadened that definition to state that science was the study of "anything." Although this may represent a change in his belief, it was not an improvement in his understandings in this area. Another change was in his belief of the importance of the role of communication in science, stating at the end of the year that it was the most important step.

Although he held fully formed understandings of most of the aspects of the scientific method, he did not ever describe the role questions play in science, although they guided much of his work during the year. In contrast, he described the importance accuracy plays in science, yet did not consider it important in his own project-based work. He had a very well developed understanding of the role that society plays in the scientific enterprise, and as a result he often described science as problem driven. In addition, he understood scientists as an integral part of the process of science. At no point in the year did he state imagination, curiosity, or serendipity played a role in science, yet he felt scientists were intelligent, at least within their own areas of study.

He strongly felt that scientific knowledge must be proven, even though it was
difficult to do so, yet once established he felt that knowledge was static and unlikely to change. He noted only during the third interview that our knowledge may evolve in science, therefore he held only partially conceived understandings of the tentative nature of scientific knowledge. Finally, he felt science could not answer all questions completely.

Donna

Donna was a studious young person who cared greatly about her grades in school. Although she was a loner throughout the year, rarely interacting with her peers in Project Seafarer, she cared very much how she was perceived by her fellow students. She was a busy individual, involved in school athletics and holding a part-time job after school. Her academic achievement was average, based on her grades, but during this, her junior year, she indicated that she wanted to pull her grades up so that she could matriculate into the college of her choice. Like most students at Woodland, she had enrolled in Introduction to Secondary Science her freshman year and biology her sophomore year. In addition to Project Seafarer, she was also taking chemistry. Donna was the only Woodland student participating in this study to take a science credit both semesters of this project-based class. First semester she pursued a credit in anatomy and physiology, an advanced biology course, and second semester she was enrolled in an independent science research credit. Many times throughout the year she indicated that science was her favorite subject, and she hoped one day to make use of her science studies as a forensic scientist working for law enforcement.
She completed five projects over the course of the year, two in anatomy and physiology and three in independent research. Her essential questions for the first semester were, "To what extent do humans have the right to use a whale's anatomy for their own resources?" and "What is the structure and basic life history of a shark?" Her three projects for second semester were more diverse in nature due to the open-ended structure of the independent research course. Her first project, which was the most extensive for the year, dealt with AIDS. The essential question was "How can I teach other people about the effect of AIDS and HIV through a hyperstudio presentation?" The last two projects dealt with dolphin intelligence and human evolution, and the questions were "How smart are dolphins?" and "What are the processes and theories of human evolution?"

As with all participants, my discussion of Donna's conceptions of the nature of science begins with the first premise of the model, "The universe is open to human description, classification, and understanding through scientific exploration," which addresses the nature of the scientific enterprise. Like both other students thus far, Ben and Bryan, Donna also believed that the universe is open to human exploration through the scientific enterprise and this strongly held belief did not change over the course of the year. She also felt this premise was "a given," perhaps partially due to the fact that she understood and perceived science as occurring "everywhere."

During our first interview she discussed how she noticed science in her everyday life, "It's like everywhere. It's crazy...like everything you see on the news, like a cure for cancer...that's all scientific related." She believed that science was the
only means by which information about our world was developed, and like the other
students, felt there was a "science" to everything. She had a complete understanding
that the universe is open to human description and classification through scientific
exploration, but only a partially conceived understanding about the many ways in
which human beings can come to know our universe. Donna held only a partial
conception of the first premise because of these beliefs.

Regarding the "everything is science" phenomena, Donna's conceptions become
clearer when the second premise, "This scientific exploration attempts to explain and
predict phenomena, compare theories, check on previous results, and generate new
questions" is examined. During our first interview our conversation went as follows:

D: How would you define science?
Donna: Um [pause] everything in the world. I don't know.
D: It's a tough question.
Donna: Everything is involved with science. If you think about
like...why we walk on the ground...
D: Is there anything that's not science?
Donna: Well I don't really know [pause] well no.
D: What about poetry?
Donna: Yeah, it's a science.
D: Is it? How?
Donna: It's a writing science.

During the third interview I asked her to define science again:

Donna: Science is just like everything. But you've got to have science to
know how to print out a poster, make a chair, make a table.
D: What's not science?
Donna: [pause] Nothing. I don't know. I just think it's everything...
D: Have you done any science in the last month or so?
Donna: Science?
D: Yeah. Done anything that you would say would be science?
Donna: No. Wait. I fixed a car.
D: Ok, what was the science in that?
Donna: I put oil in it, and the oil goes to the pistons...it's kind of like a
science.
Finally, during our fifth interview, when I asked her to define science she stated:

Um, everything. Like without science we wouldn't have like any electricity, any computers, we wouldn't have anything that makes I'm thinking of the right word, technology. That makes (life) better.

Throughout all interviews, she consistently stated that there was a "science" to just about everything.

According to Donna, the "steps" which characterize science can be seen in other areas of inquiry besides science, which also supports her "everything is science" belief. For example, during our second interview, she described how history is science:

D: Do you remember the steps of like doing science? Like the process of doing science?
Donna: No.
D: Did you ever learn those?
Donna: Yeah.
D: Did you learn them in Seafarer?
Donna: No.
D: What about chemistry? You must've gone over-
Donna: Yeah, we went over them, but I don't remember them...
D: Earlier in the school year?
Donna: Like earlier this year. We went over it in U.S. History. I don't know why.
D: Really? Are you sure?
Donna: Yeah.
D: Steps of what? What did you go over?
Donna: Like the steps of...about trying to get the data the right way and analyzing it.
D: But you did that in history?
Donna: Yeah. For like I don't know, we were doing like research papers or something...
D: Well is history similar to science, do you think?
Donna: No. I don't think it is. History just has science in it...
D: Oh, you're sort of like learning about old scientists or something?
Donna: No we don't do that. We just learn about what happened in the past, like the Revolutionary War, stuff like that.
D: So what's the science in that?
Donna: I don't think it's like science oriented. I just think the way you...
go about learning history, the steps you take. I think that's what my social studies teacher was trying to get across.

She stated "history has a science in it" when referring to the organized or systematic nature of historical inquiry, similar to Ben's conceptions. She claimed that poetry has a "writing science" to it, also most likely referring to the organized aspects of that endeavor. I believe when she stated that putting oil in her car was scientific, she was referring to the applied nature of science and technology of the combustion engine. Finally, when she stated, "why we walk on the ground" as being scientific, she was referring to that content area, gravity, as the reason for her belief. Similarly, at the end of the year she also stated that anything "having to do with science" simply made it scientific. Because of the organized nature of science, specific content areas, and because of her notions regarding the applied nature of science and technology, she held the belief that "everything is science" or at least could be.

At no point in the year did she discuss how science is predictive in nature, compares theories, checks on previous results, or generates new questions. However, her belief that science explained phenomena was fully formed and remained fixed over the school year. Without an understanding of these other aspects of the scientific enterprise, her conception regarding the second premise could only be considered incomplete.

The third premise states, "Logic, imagination, curiosity, and serendipity contribute to scientific exploration." Donna held a fully formed conception regarding this premise over the course of the year. During the third interview she stated her beliefs as follows:
I think (a scientist) would have to be artistic in a way so that you can think about the stuff you're doing in like, you can picture it before it happens, what is going to happen and like creative so you can think of different things or different ways to get to your achievement.

Later in that interview, in addition to intelligence, she also stated that "chance" would play a big role in science. She said, "If you discover something, or you don't" could sometimes depend on chance. In addition, she also described the importance of curiosity in science. At a fundamental level, she believed curiosity would help guide what a scientist chose to study. She also believed that curiosity could aid in advancing the work of a scientist once a particular goal was reached. She stated, "You want to see if you can do better...out of curiosity." Curiosity, she felt, could drive the scientific process forward.

Donna also felt curiosity played an important role relating to the next premise, "Scientific activity is a social activity conducted by individuals who are influenced by both cultural and personal factors." During the first interview she stated that people "want to know the answers" when I asked her where scientists might get their questions for study. She believed that scientists might simply make them up. During the third interview she stated that "whatever society needs" would drive the selection of questions pursued by scientists. She also said that most scientists probably work for NASA or private companies. During the fifth interview she stated that both curiosity and societal problems or needs could effect what scientists study. She stated scientists "investigate things they're curious with" and also "big companies" could direct scientific work. In providing an example of a big company, she cited a regional defense contractor who she thought builds missiles, and stated scientists work there.
Her beliefs regarding science as a social activity changed over the course of the year toward a fully formed understanding, however there is no clear evidence to support why. Although she believed that curiosity still plays a role in science, she also came to understand the role society can play in the scientific enterprise.

With regard to the role personal factors might play in science, her understandings did not change over the course of the year. She believed that if scientists followed the same "steps" throughout the course of completing a scientific study, regardless of who they are, they would achieve the same results. She did not indicate that different scientists may interpret results differently depending on their prior experiences or other personal factors. She did not describe science as a human endeavor. When I inquired about scientists from different countries, she indicated that she had "no idea" how scientists in different countries might pursue science. Her understandings of this aspect of the premise were only partially developed. Her conception of the overall premise was therefore incomplete.

The final premise which characterizes the scientific enterprise states "Questioning, data collection and analysis, drawing of conclusions, and communication are the major phases which characterize the scientific endeavor." Donna had difficulty articulating the steps of the scientific method over the course of the year. During our first interview our conversation went as follows:

Donna: I can't do it right off memory. Well, I know some of the steps. There are five steps and I forget it.
D: Did you learn these in a class?
Donna: Yeah, ISS first year.

In the second interview, she stated regarding the steps, "We went over them, but I
don't remember them." During the third interview her description of the steps was a little more revealing. "I don't know. What is it? It's like data, collect data, no find a collection, collect data, wait, interpret it, no, then you do an experiment and then you can come up with a conclusion. I forget." During the fifth interview she also claimed not to remember any of the steps, yet was also able to describe a few of them:

D: What about the scientific method? Do you remember the steps to that?
Donna: No.
D: Not at all...?
Donna: It's like interpret data objectively is like the last one. No wait, conclusion was the last one.
D: Conclusion. Uh huh.
Donna: The one before that is interpret data objectively.
D: What do you mean by objectively?
Donna: Like un-opinionated or something.
D: Oh, uh huh...
Donna: Define the problem. Formulate.
D: Uh huh.

Like many students, she explained that she had learned the steps to the scientific method in a general science course in middle school/junior high school or at the beginning of their high school career. In Donna's case she also said that she went over the steps in her history class and that they covered the steps in the beginning of the year in both her biology and chemistry classes.

However, she said that she did not cover the steps in any fashion as part of Project Seafarer. During our formal interviews she was only able to list some of the steps at various points throughout the year, and at no point was she able to discuss any of the scientific method in a complete manner. However, because of follow-up discussions held during participant observation sessions, I believe she did hold a full
understanding of communication in science, and mostly formed understandings of the balance of the steps. She was able to discuss each of the phases which characterize the scientific endeavor as we informally talked throughout the year. During our formal interviews I felt she focused on trying to "list" these steps in the "correct" order, and for fear that she might get one out of place she claimed not to know the steps at all.

During the first interview Donna mentioned questions when discussing scientific knowledge and I asked her what questions had to do with science, if anything, and she responded:

Well, if people didn't ask questions, if Newton didn't ask the question, "Why did the apple fall on my head?" or something like that, he wouldn't really care why it happened. So, we wouldn't really know about his first law.

This passage, from the very first interview, shows that she did see a role of questions in guiding science, and, in fact, she did hold this belief over the course of the year even though she did not rely on questions to guide her own work.

During the second interview when I asked Donna about developing questions for use in her own projects, she stated that "It took me a week and a half to think of one...one that would interest me." During the third interview after she stated that her third project was going to deal with AIDS, I asked if she had developed a question and she replied, "Not yet, no," and gave the following reason:

I think it's hard because I'm the type of person who wants to get everything into the presentation and then it's kind of hard to find one central question to like basically sum up the whole presentation.

Immediately following the presentation of her AIDS project I also inquired about the question for her project:
D: Was there a question...
Donna: Yeah. It was like "How can I teach other people about the effects of AIDS and HIV through a hyperstudio presentation?"
D: And did you have to present an answer at all?
Donna: I did. I said like just by doing the project I informed people about it.
D: And when did that question come into being? Like at the very beginning of the project or was it something you developed along the way?
Donna: I thought about it last night.
D: So not until the very end.
Donna: No. I don't think about my essential questions until like, I see what I have and then I like think of one that'll help. The one I thought of last night was pretty general.

Her project based on the topic of AIDS included information on the symptoms of AIDS, the cycle of the virus, the changes to the human body, and she also mentioned some medications currently available to help treat the symptoms of the disease. Her question, developed at the last minute, seemed forced or contrived. She had selected the topic of AIDS and conducted her research without the help of a question. The night before her presentation she knew that posing and answering a question was part of the evaluation of the project, so she developed one that she knew she could "answer." One reason that she was able to complete her project without a question is that, like both Ben and Bryan, her notion of research was merely gathering and compiling information from the internet. For this project, she gathered what she could, put that information together, and retro-fitted a question to the project.

During our last interview she expressed how much she disliked essential questions in Project Seafarer. She felt they limited what she could do as far as research for a project, and stated once again that she did not develop them until the end of her projects. She also said that it didn't matter if questions were broad or
narrow, and as a result had no notion of researchable versus guiding questions. With regard to why she felt questions could guide scientific work, such as Newton and the apple, yet not guide her own work, may have been due to that fact that she didn't see herself as a scientist:

D: Do you consider yourself a scientist?
Donna: No.
D: How come?
Donna: Because I haven't done enough science to know...I haven't acquired enough knowledge to consider myself a scientist. I don't think the world would consider me a scientist.

Donna held conflicting understandings regarding the role of questions in science. In addition, she didn't need a question to begin searching for information on the internet, she just needed a topic. Most of the topics which Donna chose she developed while reading magazines, such as National Geographic, or watching television, including the Discovery Channel.

Regarding data collection and analysis, during the second interview she distinguished between the type of projects that she pursued in Seafarer and the projects she conducted in her chemistry class:

D: So do you do any data analysis in chemistry at all?
Donna: Chemistry we do like compounds and labs. A lot of labs...
D: Do you collect any data in those labs?
Donna: Yeah, right now we're doing an acid rain lab.
D: Cool. What are you doing?
Donna: Collecting rain from outside in certain parts of this place and we test the pH to see if it's acidic.
D: So what's the data?
Donna: See if it's acidic, and we compare to other parts of the country.
D: So do you do anything like that through Project Seafarer?
Donna: No.
D: So it's a different kind of project?
Donna: Yeah.
D: Are they both science, though?
Donna: Yeah.
D: Does one seem more science than the other?
Donna: No. I just take it two different ways.

Donna experienced several steps of the scientific method in her chemistry class that she did not experience in Project Seafarer. Because of the topics of her projects in Seafarer she considered them "science," yet recognized that they were different from the labs in her chemistry class in which she actually collected and analyzed data. As she stated, she feels they are both "science," yet different. Regardless, from this example it is clear she holds a basic understanding of what data collection and analysis entail, even if she did not learn these aspects from Project Seafarer.

With regard to data interpretation, or drawing of conclusions, it is important to note that during the fifth interview when she mentioned data interpretation, she stated that this interpretation should proceed "objectively." This relates back to her conceptions regarding the previous premise in which she stated that scientists would always achieve the same results if they conducted the same study and followed the same steps. Clearly, she believes that scientists should be, and are indeed objective when interpreting data. An understanding that scientists can not be entirely objective or detached from the process of science is what I would characterize as a sophisticated belief. It is one that students should begin to develop over the course of their high school career, but that Donna has not yet begun to develop. However, she at least held partially formed understandings of these aspects of the premise.

With regard to the communication of results, Donna stated during the third interview that at the conclusion of a scientific study scientists would "declare to the
scientific community" that they have reached the objective of their study. She said this could be accomplished through magazines or the news. During the fifth interview she similarly stated that scientists should publish their results at the end of a study in order to share their information. During the final formal interview of the year she stated that "presenting is fun" and that when she knew a topic well, she did not mind presenting. She saw presenting as the logical conclusion to her work and to a scientific study. She held her fully formed understandings regarding the communication of results over the entire year. Overall, however, her conception of this premise was only partially formed.

The first premise which characterizes scientific knowledge states that "Scientific knowledge demands evidence, and is testable through the scientific enterprise." Donna's conception of this premise was fully formed and consistent over the course of the year. During our first interview she stated the scientific method is the means by which you find answers in science. During the second interview she stated that scientific information must be "proven" in order to be scientific. During the third interview she stated, "It has to be done the right way for people to take it seriously," when discussing if scientific facts have to be proven. That right way, she said, was through a scientific experiment. Similarly, in the fifth interview she said you need "proof" in order for other scientists to take your scientific work seriously.

Regarding the next premise, "Scientific knowledge cannot provide complete answers to all questions," there is very little data in the transcripts. It is impossible to describe her conception in this area over the course of the year because of an apparent
oversight in my line of questioning.

Concerning the final premise of the model of the nature of science, "Scientific knowledge is tentative, developmental, and subject to revision," her understandings developed somewhat over the course of the year. During the third interview she stated that scientific knowledge could "become out of date," however had difficulty providing an example of what she meant. During the fifth interview when I asked her if scientific knowledge could become out of date, she replied, "No. Because there's like laws that like Newton thought of like back in the past that are still used today like all the time." Although she never fully articulated the developmental nature of scientific knowledge, her understandings partially evolved to the belief that older scientific knowledge at least has some value. This incomplete change may represent an evolution in her beliefs toward a fully formed conception, although at the conclusion of this study she still did not hold sufficient understandings of the developmental or tentative nature of science to have her overall conception characterized as complete.

The next sub-section discusses Donna's opinions of this project-based class. The following sub-section is a brief summary of her conceptions of the nature of science.

**Conceptions of the Project-based Class** - From the very first formal interview, it was clear that Donna understood the differences between a traditional science class at Woodland and the science credit she was pursuing through Project Seafarer. She described on of those variances as, "(I'm) basically on my own. I have to give myself my own due date. I have to do all my own work, my own responsibility..." Later in
the year she stated that because she had autonomy over much of what she did in 

Seafarer, she worked hard and found it interesting:

It's important to me, you know. I don't want to find, I don't want to know that 22.4 decimeters cubed is like the gap molar thing or something (regarding chemistry class). I don't find that interesting and I'm not going to learn about it if I don't want to, but if I want to learn about AIDS or dolphin intelligence, I'm going to.

Additionally, in the final interview of the year, she stated, "Seafarer keeps me on my toes because I have fun doing it." She clearly enjoyed the academic segment of this class much more than the boat building portion of the class. As early as the second interview, she stated:

I kind of expected like people in Seafarer to have equal interest in academics than in the boat itself. But I think people are so focused on the boat and if it's going to get done, I think they're just worrying a little too much about it. So like everything they want us to do is we got to work on the boat, we got to work on the boat. And I don't think they spend enough time on academics.

Perhaps because she was somewhat of a loner, she enjoyed working on her individual projects as opposed to working with a group of people on the boat. She said several times over the course of the year that she did not like relying on other people, and only trusted herself to get what was needed. Although students were encouraged to interact with other students during the academic portion of the project to get feedback on the progress of their work, she rarely participated in this form of informal communication with her peers.

Donna earned excellent grades her junior year. At the end of the year she still wished to be a forensic scientist someday. She is a motivated student who, I suspect, will succeed at whatever she pursues.
Summary - Like all students thus far, Donna believed the universe was open to scientific exploration by humans, but did not consider non-scientific ways of inquiring. Because of her broad beliefs concerning the applied nature of science, the organized nature of science, and what constitutes scientific content she described "everything" as science. When asked to define science she never discussed the predictive nature of science, comparing theories, checking on previous results, or generating new questions, therefore her conception regarding the second premise was incomplete. However, she did hold a fully formed conception regarding the roles serendipity, or as she stated "chance," imagination, intelligence or logic, and curiosity play in the scientific enterprise.

Her beliefs changed over the course of the year regarding science as a social activity, ultimately developing a full understanding as the year progressed. At the beginning of the year she stated individual curiosity led to scientific questions, but by the end of the year believed that although curiosity must still play a role, societal problems and needs also directed the scientific enterprise. She held only partially conceived understandings of the role personal factors might play.

Donna held somewhat conflicting beliefs concerning the process, or steps, of science known as the scientific method. Although she believed that questions were important to scientists, she did not make use of them when completing her own projects. She did not need questions to gather and compile information, which is what she considered research, she only needed a topic to complete her work. As a result, she did not distinguish between researchable and guiding questions and her
understanding of questions was incomplete. She developed very broad and often contrived questions at the very end of her projects to meet the criteria for the project evaluation.

Although she partially understood data collection, analysis, and drawing of conclusions within a scientific context, it seemed that she did not experience these in Project Seafarer, but in a science class she was also taking this year. She believed that these steps should be accomplished objectively, and felt that scientists could achieve this goal. With regard to the communication of results, she saw this phase of the scientific enterprise as important for scientists as well as for her own project-based work and held a fully formed understanding.

Donna held a full conception of the premise which stated that scientific knowledge demands evidence, often citing the requirement of "proof" and "the right way" of doing science. Her understandings of the developmental nature of science changed over the course of the year, first believing that scientific knowledge becomes out of date, but later coming to believe older knowledge has some value. However, she never fully described the developmental or tentative nature of knowledge, and therefore she held only a partial conception of this premise. Finally, regarding scientific questions and whether they could be fully answered, there is insufficient data to describe her beliefs.

Linda

Linda was a popular, outspoken senior who was involved with school activities
such as cheerleading. Her grades were below average in many areas, in part due to her excessive absences from school. During the course of this study she missed a great deal of school, sometimes a week or two at a time, due to various non life-threatening illnesses. Since she was not planning to attend a four year college, her class load was relatively light her senior year. Although she had taken Introduction to Secondary Science, biology, and chemistry through her junior year, she was not enrolled in a science class for her last year at Woodland. She did not particularly like science, stating she hasn't thought about it since her chemistry class, and never watched science-related television programs or read magazines or books dealing with science.

For Project Seafarer, she was enrolled in a journalism credit for the first semester and an independent study art credit for the second semester. Following her senior year she hoped to receive training in graphic design, and work in the field of desktop publishing.

Linda completed five projects over the course of the year, four in journalism, and one large project for her art credit in which she worked in the area of computer graphic design. Her first journalism question was "Will there be a whaleboat?" Like Bryan, she was required to write various articles for "publication," although they were not necessarily submitted for publication anywhere. For her first project she surveyed students at Woodland and wrote an article based on what the student population thought about Project Seafarer. Her next two projects were what she described as opinion or editorial articles, and were based on the questions "How do students in Seafarer see the interns?" and "Who donated materials to Project Seafarer?" Her final
journalism project had no essential question, but gave her the opportunity to contribute editorially toward the publication of the Deadwood, the class newsletter.

Her question that guided her work for both quarters in art was "How can I use graphic design to help answer the question What is Seafarer?" In order to accomplish this she developed a short animation which showed the construction of the boat. This project was included at the beginning of another student's video project that was based on the question "What is Seafarer?"

The first premise states, "The universe is open to human description, classification, and understanding through scientific exploration." Like all students, Linda believed that the universe was indeed open to scientific exploration. She held this fully formed understanding over the course of the year. Toward the end of the year, when I asked her if there was a common goal to all of science, she responded similarly to Ben when she said, "Probably to dig deeper into things and find out how things work." She indicated at many points throughout the year that science could find out how things work.

Although Linda indicated in the very first interview that science is "the study of everything," unlike other students thus far, she did not revisit this notion that everything is science in subsequent interviews. Although her definitions of science over the course of the year indicated that she felt science was a broad and encompassing endeavor, she did not hold similar conceptions to other students who stated that "everything is science," or at least has a science to it. During the first interview, she mentioned construction workers when providing an analogy that just as
these workers must know certain things to do their job, so must scientists. I made use of this opportunity to ask her if she thought construction workers were scientists, and she responded:

No, I don't think so...I don't think they are exploring new things or finding new ways [pause] like when they found the nuclear energy and stuff like that. The scientists found the nuclear energy and stuff like that. That was a new way to create energy. I don't think construction workers are trying to find a new way to create something else.

As stated earlier, she did not particularly enjoy studying science in school, and said she has not thought about science since her science classes in years past. Because she rarely thought about science and didn't care for it as an academic subject, perhaps it's not surprising that she didn't hold similar conceptions to her peers with regard to the "everything is science" phenomena. Although she did not believe everything is science, she still did not address other ways of knowing, besides scientific ones, when discussing how humans "find things out" about the universe. She held only a partial understanding regarding this aspect of the premise, and therefore her conception of the entire premise was incomplete.

With regard to the second premise of the model, "This scientific exploration attempts to explain and predict phenomena, compare theories, check on previous results, and generate new questions," Linda stated during the first interview, "Science? It's the study of everything. What the world is made up of and all of the things in it. The plants, the people, animals, matter, chemicals." During the third interview, our conversation went as follows:

D: I want to see if you can define science for me.
Linda: Well [pause] the study of, biology is the study of living things
and things like that [pause] science is investigating into why things work.

D: Uh huh.
Linda: I don't know.

I asked her to once again define science during our fifth formal interview:

Linda: I'll say the study of things. I don't know, uh-
D: What kind of things?
Linda: I don't know...I don't know.
D: That's ok.
Linda: [pause] Chemistry you study like chemicals and things like that, and biology you study like life. So it's just like, science is just like overall everything together, but it might be chemistry and biology.

Over the course of the formal interviews, even though I explained to Linda that I was not necessarily looking for "correct" answers, but wanted her beliefs and opinions regarding various science related topics, I feel she still wanted to provide me with the "right" answer. I believe this is why she often hesitated and repeated the phrase "I don't know" when I posed this question. She consistently defined science as exploring and explaining new things while encompassing both biotic and abiotic factors, mentioning chemistry, biology, matter, plants, animals, and chemicals. As stated earlier, her definition was broad, yet still seemed to be focused within the discipline of science, and not incorporating "everything" as science. Her understanding that science attempts to "explain" phenomena was fully formed.

However, she never discussed the predictive nature of science, science generating new questions, or science comparing theories. At only one point in the year did she mention scientists checking on their results when she stated that scientists do their work "over and over and over" again. Therefore, her understanding of this aspect
of the premise was only partially formed. Her overall conception of this premise, which remained unchanged over the year, was incomplete based on the model presented in this work.

The next premise states, "Logic, imagination, curiosity, and serendipity contribute to scientific exploration." Linda developed a fully formed conception of this premise over the course of the year. During the first interview she stated scientists must be "smart" when it comes to science. She believed that her chemistry teacher from the previous year was a scientist because he held a doctorate. That advanced degree, she believed, showed he was smart and that his intelligence enabled him to be a scientist. In addition, she indicated that she believed people are generally curious, and that curiosity makes people ask "why," which is indicative of science. In the third interview she also mentioned that scientists inquire about why things are the way they are:

I think they have to be interested in what they are doing. Scientists want to know more about why things are the way they are. Why do oxygen and hydrogen mix together to make water? I mean they have to be interested in that type of area.

During the fifth interview she specifically mentioned creativity in science, stating, "(Scientists) have to be creative because they'd have to think of new and different ways to solve problems." In addition, she added that scientists might "stumble upon" things that they were looking for, and that luck certainly contributed to the scientific endeavor.

In the beginning of the year she felt intelligence, or as the model states "logic," driven by curiosity, was the key factor in doing science. However, by the end of the
year she added creativity (imagination) and serendipity as also being important to the scientific enterprise. At the end of this study, she described all of these factors as contributing to science which represented a change in her understandings. There is no data to suggest why her beliefs evolved.

"Scientific activity is a social activity conducted by individuals who are influenced by both cultural and personal factors" is the next premise of the model. Linda held partially formed understandings of aspects of this premise, which remained unchanged over the year. Although at one point during the first interview she mentioned that scientists "get paid" to find things out, she never mentioned societal problems or needs as influencing what scientists study. During the third interview she summed up her beliefs when she stated that scientists "come up with their own ideas" about what they study. When I specifically mentioned present day scientific research, and asked her who might be supporting that endeavor, she responded, "I have no idea."

With regard to personal factors which may influence scientists and ultimately the process of science itself, like Ben and Donna, she believed only external factors would effect the results of an experiment. During the first interview she stated:

You have to do it in this and this condition. It has to be 70 degrees out, it has to be not a lot of moisture in the air. If the person does it exactly the same and the results don't come out right then they know that something is wrong...

Similarly, during the fifth interview she stated, "It has to be like the same...like say one did it in cold weather and another did it in hot weather, they might get different results." She did not feel that scientists themselves may be a factor in the scientific
enterprise. She held incomplete understandings of all aspects of this premise, resulting
in an incomplete overall conception.

The final premise which characterizes the scientific endeavor states,
"Questioning, data collection and analysis, drawing of conclusions, and communication
are the major phases which characterize the scientific endeavor." Linda claimed
several times over the course of the year that she did not remember the steps or phases
of the scientific method. During the first interview she was unable to list any of the
steps when I inquired about them. In the second interview, our conversation went as
follows:

D: Do you remember learning the scientific method?
Linda: I remember learning about it. I don't remember anything about it
now. I know that we did learn it.
D: Do you remember the steps...?
Linda: No.

During the third interview when I inquired about the scientific method, she was only
able to describe one aspect of these phases:

D: What about the scientific method, are you familiar with that?
Linda: I forget what the steps are, but-
D: Do you remember any of them?
Linda: You have to create a hypothesis, I remember that one.
D: Which means what?
Linda: [pause] It's what you think is going to happen...

During the fifth interview, I once again inquired about the scientific method, and our
conversation unfolded as follows:

D: What about the scientific method? I know we talked about that
before. Do you remember those steps?
Linda: No.
D: Any of those steps? When was the last time you learned it do
you think...?
Linda: At least a year ago...probably two years ago.
D: Do you ever remember using them or just-
Linda: In ISS we used to have to use them when we wrote up our lab reports and things like that. But I don't remember them.
D: So you haven't used them recently?
Linda: No.

Even though she claimed she had not utilized the steps to the scientific method in several years, they came up during the second interview when we discussed her initial project in which she surveyed her peers to determine their views on Seafarer:

D: (Can you define) data?
Linda: Information that you collect.
D: Yeah, and do you use any data in your projects? Would you say you have collected any data during Seafarer this year?
Linda: Yeah, like I think of data as numbers sometimes more than like words or information. If you say words are information, then I had to collect for my first article that I wrote about the whaleboat because I sent out surveys and had to take all of the information in after I got them back. So I did collect data for that one...
D: I remember in the beginning you had a stack of those answers. What did you do with them?
Linda: I don't know where they are.
D: No, I don't mean that. (laughs) How did you go from a stack of answers to the end of your project...?
Linda: What I did first was I took the first question and I divided them out into yes and no kind of answers and then a why. That's what it was, yes, no, and why. I took all the yes's and put them in a pile, I took the no's put them in a pile, and then everybody else I don't know, or no clue...I put those in another pile. Then afterwards I went through the yes's and took the similar ones for why and tried to separate them like that.

Linda only held a partially formed conception of this premise, however she made use of several "steps" during her first project. It seemed that it was not made explicit to Linda that during this project she collected and analyzed data in a manner which is consistent with the phases of the scientific endeavor. Because Linda was pursuing a
credit in journalism, her question (Will there be a whaleboat?) was not a scientific question and may explain why her use of the scientific method was not made explicit to her. Her understandings remained unchanged over the course of the year concerning elements of this premise, except perhaps with regard to data. I believe because of her experiences with her first project in Seafarer, she now considers data in terms of both numbers and in terms of words or "information."

Referring to her own projects, she said this about questions:

For me, it's something that gets you going. It's like that's my starting point and then I go from there. Sometimes I get a little off track, but it's OK because sometimes I come up with something better than I would have if I stayed right on track.

Linda did not find questions limiting, rather they guided her projects. She stated that she thinks of her questions throughout the course of working on her projects, and tries to answer them by the end. However, she did not discuss questions as contributing to the scientific endeavor.

Like many students, Linda saw the steps of data collection, analysis, and drawing of conclusions as closely related. However, she had little to say about them when explicitly asked except with regard to her first project. Her understandings were very incomplete. Linda had fully formed understandings of the final phase of the scientific endeavor, the communication of results. She was aware that scientists often published and discussed their results. During the first interview, when I inquired about what happened at the end of a scientific study, she replied, "They publish it in journals." Regarding her own project work, she said she enjoyed sharing the information from her projects with her classmates, and was proud of the article which...
appeared in the Deadwood, which was based somewhat on her first project.

The first premise of the nature of scientific knowledge states, "Scientific knowledge demands evidence, and is testable through the scientific enterprise." Linda's conception of this premise was fully formed and unchanged over the course of the year. In the first interview, she stated in order to develop scientific knowledge one must "have to do experiments...find solutions." Again in the third interview, I inquired about making claims which were scientific:

D: Let's say I make a claim that I think that this note pad can provide limitless energy for this whole town forever. Is that a scientific fact?
Linda: If you have facts to back it up, maybe it could be, but if you stated it would, then it wouldn't be. You have to give facts to back it up and experiment and data and stuff.

Later in the year she also discussed "proving" information in order for it to be considered scientific.

Regarding the next premise, "Scientific knowledge cannot provide complete answers to all questions," Linda's understandings changed over the course of the year. In the beginning of the year she stated that scientists often go through "a lot of trial and error" but eventually find out the truth about things, indicating they can fully answer their questions. During the third interview I specifically asked her:

D: Can a scientific question be answered fully?
Linda: [pause] Mostly yeah, I don't know when it wouldn't be unless they couldn't find information. I think mostly they can be.

By the fifth interview, her beliefs had changed somewhat:

D: Can you answer a question fully? A science question?
Linda: I don't know. You can say I have the answer up to this point but it could change tomorrow because they might come up with a
new technology to find something different. But like you can do maybe to this date you have this much knowledge...

D: And can science find like the truth about the world and stuff?
Linda: It depends on, I don't know, to an extent I think, because you can't, it can only be like an up to date answer.

By the end of the year she was beginning to re-think her notions regarding this premise. She cited new technology as potentially contributing new information in the pursuit of questions, and therefore believed that perhaps scientific questions could not be fully answered after all. Perhaps it was her experiences with state-of-the-art technology in Seafarer which contributed to this change, but there is no data to clearly support that. At the conclusion of the study I would characterize her conception as still only partially formed, but certainly matured from the beginning of the year.

Her beliefs about this area closely relate to the next premise, which states, "Scientific knowledge is tentative, developmental, and subject to revision." Linda's understandings about the notion of science as developmental were fully formed and fixed over the course of the year. During the first, third, and fifth interviews she described older scientific knowledge as serving as the "basis" for new knowledge. Once again she cited technology as potentially contributing to new knowledge. She provided a mathematical example to illustrate her point that knowledge was tentative and developmental. She pointed out the calculations regarding \( \pi \), and noted that we still know it is equal to 3.14 out to two decimal places, but that new technology adds numbers at the end of the decimal places all the time. She held a full conception of this premise over the entire school year.

The next sub-section describes Linda's opinions of Project Seafarer. The
following sub-section briefly summarizes her conceptions of the nature of science over the course of the year.

**Conceptions of the Project-based Class** - As stated earlier, Linda was quite often absent from school. As a result, she was always pressed for time to complete her projects in *Seafarer*. Unlike Donna who disliked the boat building portion of the class, Linda enjoyed both the academic and boat building segments of the class. At the end of the year when I asked her what she liked least about the class, she responded "nothing," indicating she pretty much liked it all. Like many students she described the class as "hands-on," and when I asked her if she would recommend the class to other students, she responded:

Yes. Well, it depends on what kind of learner you are. Like if you're the kind of person who likes to do hands-on type stuff then it's a great class for you, but if you like to sit down and study stuff like out of a book and just like spit it back out then the class isn't really for you.

She described herself as a hands-on learner which is why she enjoyed building the boat so much. She worked on the crew which developed the centerboard and mast. She also liked the teamwork consistent with this aspect of the class.

In contrast, she did not enjoy working alone in the academic aspects of this project-based course. Toward the end of the year she described how she got frustrated sometimes working with computers, and felt there was little guidance from her peers or teachers. In trying to develop the animation for her independent art credit she bounced back and forth between five different software applications for week after week during the second semester trying to develop each individual animation cell and eventually putting them together to produce the illusion of motion. By the end of the
year she did manage to produce a cartoon animation which lasted approximately 10 seconds which showed the boat being built. As stated earlier, it served as an introduction to another student's video which described the Seafarer class. It was meant to be comical, and serve as an eye catching introduction which showed the boat being assembled very, very fast. She felt if she had more guidance from teachers or help from her classmates she could have made a longer, higher quality product.

Although in the end, the product did not seem as "impressive" as she originally envisioned, she did admit that she learned the various pieces of software, and struggled and overcame many obstacles. For Linda, the success of her final project was very much defined by the process, not the product. One goal of this class was to have students experience both these aspects of project-based work, and I believe Linda certainly did. At the end of the year she still liked graphic design enough to pursue it as a career. She was accepted into a two year training program at a local technical school and was looking forward to her chosen profession.

Summary - Like all students, Linda believed that the universe was open to scientific exploration, and held that belief over the course of the year. However, unlike many other students she did not feel that "everything was science" or that there was a science to everything. Because she did not address other ways of knowing besides science, her conception of the first premise was incomplete. Over the course of the year she defined science as exploring new things while encompassing biology, matter, plants, animals, and chemicals. Her definition was broad, yet still seemed to be focused within the discipline of science. She never discussed the predictive nature of
science, science generating new questions, or science comparing theories, and only briefly discussed science as checking on previous results. Her overall conception of this premise, which remained unchanged, cannot be considered fully developed based on the model presented in this work.

In the beginning of the year she felt intelligence, driven by curiosity, was the key factor in doing science. By the end of the year she added creativity and serendipity as also being important to the scientific enterprise. These new beliefs represented a change in her understandings, which resulted in her having a fully formed conception of this premise by the end of the year. Linda held a fixed, partial conception regarding the next premise. She never mentioned societal problems or needs as influencing what scientists study, believing that scientists simply came up with their own ideas. In addition, like Ben and Donna, she felt only external factors might influence a scientific study, not scientists themselves. She did not see science as a human endeavor.

Regarding the final premise which characterizes the scientific endeavor, Linda did not have a full conception. She made use of various steps of the scientific method during Project Seafarer, even though she claimed not to have used them since a science class several years back. It was not made explicit to Linda that during her first project she collected and analyzed data in a manner which is consistent with scientific exploration. Concerning data collection, analysis, and drawing of conclusions, like many students she saw these steps as closely related, but held only incomplete understandings of them. Linda held a full understanding of communication in science,
aware that scientists publish and discuss their results in order to share information.

Linda held a fully formed conception of the premise dealing with the proof required in order to classify knowledge as scientific. At the conclusion of the study I would characterize her conception of the next premise involving questioning as still not quite completely formed, but matured from the beginning of the year. She began to think that scientific questions could not be fully answered, and in part based her changing beliefs on new technology constantly available to re-examine scientific questions. Regarding the notion of science as developmental and tentative, Linda's conception was fully formed and fixed over the course of the year, once again citing technology as potentially contributing to new knowledge.

Larry

Larry was a junior at Woodland during the course of this study. Throughout our interviews, both formal and informal, he seemed very interested in the questions I posed, as well as quite thoughtful in his responses. He enjoyed talking "science," perhaps because he liked the subject in school, and often mentioned that he thought a lot about science even after school hours. He did well in school, and participated in extracurricular activities such as the annual Woodland yearbook.

During his junior year, in addition to the environmental science credit he pursued for first semester in Project Seafarer, he was also enrolled in a chemistry course. Prior to his junior year he completed biology in tenth grade, and during his ninth grade year in which he was home schooled he studied both biology and
chemistry under the guidance of a parent. He was also home schooled during his fifth grade year, however the rest of the years he enrolled in classes in the Woodland district. He particularly enjoyed biology, stating during our first interview, "It interested me a lot...we dissected pigs and even though I kind of thought it was disgusting, it was interesting, very interesting." During the second semester he enrolled in a literature credit, even though he stated he would have rather stayed with environmental science. Since he was surely college bound, being ranked near the top of his class, he was counseled to pursue a certain amount of credits in various academic areas. He was unsure of a career he wanted to pursue.

He completed six projects over the course of the year, two projects in environmental science and four in literature. The questions for the environmental science projects were "Is the ocean a good enough barrier to prevent the spread of a lethal disease?" and "What is the difference between a tornado and a waterspout, and how are the methods and equipment for predicting such violent storms different from a hundred years ago?" The first project used information derived from an encyclopedia on CD-ROM and the internet to examine diseases, including information about viruses and bacteria, and determine where certain diseases are most prevalent around the world. The second project made extensive use of the internet including the various WWW sites available about weather, in addition to an interview with a classmate's father who studied meteorology in college.

Two of the projects he completed in literature were minor projects in which he read various books and summarized the plot and characters, however two projects
were more substantial and posed the questions, "What were some of the dangers of ocean travel, and how did they affect literature about the ocean?" and "How did attitudes about the Titanic change after it sank?" There was miscommunication concerning the project which dealt with the dangers of ocean travel and literature which caused Larry to receive an incomplete for a portion of the second semester. He interpreted the question as dealing with the authors of the books he read, while his cooperating teacher and intern helping to guide the project were thinking about the dangers of the ocean in relation to the characters within a given story. However, as will be discussed later, once this was worked out he presented his project receiving full credit. The other major literature project flowed more smoothly. He investigated historical and technical information about the Titanic, as well as reading a fictional novel about the shipwreck.

Regarding Larry's conceptions of the nature of science, as with all participants, I will start with the first premise of the model, "The universe is open to human description, classification, and understanding through scientific exploration." Larry held a fully formed conception of this premise. His beliefs were more mature or advanced than the other students at Woodland, and did not evolve over the course of the year. He addressed the notion that humans have the capacity to examine the universe in a way which is scientific, but may not necessarily ever come to know all there is to know. He stated, "I think there are certain things that are unexplainable and they will remain that way..." as well as "I just think that there are some things that will never be completely found out in its entirety," when discussing some limitations.
of our scientific exploration of the universe.

Unlike other participants he did not feel that "everything" was science. Although Linda also did not hold the belief that everything is science, as stated earlier, she rarely considered science outside of science classrooms. Larry, on the other hand, enjoyed science immensely. He thought about it a great deal, especially when watching science-related television programs and reading science-related material on the internet. From the very first interview we discussed ways of knowing which are not necessarily scientific:

Science deals with the truth of where we came from. I mean I'm a Christian, I believe in creation...we could argue about that forever...I'll call it a theory, neither theory can be excepted without some faith of something. Evolution doesn't involve a faith in God, but it involves a faith because matter cannot be created nor destroyed but yet we have it, so you have to believe that somewhere somehow, something happened where matter was created, or not created, somehow it got here, we know that. But either way, we haven't been able to answer how...so either way, it takes some acknowledgment that we don't know.

During the second interview when discussing some differences between science and other areas of study within school, he stated "(science) sort of is without looking at a [pause] a theological, spiritual...it just has to do with how things work together, material things." He summed up his position succinctly regarding scientific ways of thinking in the third interview when we discussed characteristics of scientists:

I think it's just a mind set...I think they might do the exact same stuff as someone who is not trying to involve themselves in science...one person may throw a bunch of stuff in the washing machine, sort of the detergent in and put it on and let it run, but another person might be sitting there thinking, 'gee I wonder what causes this detergent to break up the molecules of the dirt that allows the water to carry it away from the clothing?' and I think the person who is analyzing that is more of a scientist than the person who's not.
Clearly, Larry understood science as one way of thinking, exploring, and ultimately knowing. Although he felt that two individuals could participate in similar experiences, one person could be doing science while the other person would not because of the way one individual purposefully frames and considers certain questions. This certain way of thinking and questioning, Larry felt, was scientific. In addition, because of his devout religious beliefs, he experienced other ways of understanding the universe besides science.

The second premise, "This scientific exploration attempts to explain and predict phenomena, compare theories, check on previous results, and generate new questions" served as a definition of science. During the first interview, our conversation went as follows:

D: Can you define science? I mean how would you define science?
Larry: It's a study of [pause] things around us maybe that we don't know. [pause] Good question.
D: Do you ever remember discussing a definition of science in classes...?
Larry: Well in biology, biology is the study of life, chemistry is the study of matter, but I don't know that, or I can't remember that we ever basically set out the word science.
D: What do you mean by a study? Like the study of life or study of things?
Larry: Ok, study of life would be uh going through, well the word study is [pause] oh, man [pause] it really gets you thinking. It's not review.
D: Why? What's a review?
Larry: Well a review is going over things that are already known and science isn't stuff that's always already known.

Later in that first interview, like many students, he used the phrase "how things work" when describing what science can tell us. During the second interview he described science as "core" work that is "basic." He also discussed the hands-on nature of
science stating that it usually entails working with matter, biology, or chemicals in some fashion. During the third interview, he stated, "I think science is researching what affects us and affects the environment and affects our world. And the basic material elements that come into that..." In addition, he said experiments, problem solving, and social sciences are all characteristic of science. During the fourth interview he similarly explained:

Larry: I think science is still the study of what's around us, what affects us in life. You know, like in a physical science or biology or chemistry, it's the matter that affects us or sometimes not affects us because when you study certain chemicals it's like, it might be kind of hard to relate how that affects you and your body but it's still what's around us, the matter that's around us, what's going on. And like a social science is like how do other people affect us, how do groups affect each other.

D: So you include social science in the definition of science?
Larry: Yeah. Yeah. And even other sciences.
D: Such as?
Larry: I guess psychology is a science of studying what is going on in people's minds or what affects people's psyches, whatever you want to call it.

During the fifth interview he broadly discussed how science is the study of what effects humans "in any sense." By the final interview he had included "exploration" in his definition and emphasized that "science more than most subjects and studies has more of a directive towards...it can be used more to help people."

Although his view of science being able to explain certain phenomena developed into a full understanding over the course of the year, and included such notions as problem solving and the applied nature of science, at no point throughout the year did he specifically discuss checking on previous results or comparing theories as being indicative of science. I believe his project-based work, specifically the
tornado project, fostered a change in his understandings which ultimately led him to believe that science can be used to help people in an applied manner. As will be discussed under the second part of the model which deals with scientific knowledge itself, he did view science as generating new questions. He also understood that science involves prediction and the generation of new knowledge. However, his overall conception of this premise was only partially developed.

The next premise states, "Logic, imagination, curiosity, and serendipity contribute to scientific exploration." During the early part of the year he mentioned "curiosity" and "wondering" as being essential to science, and during the third interview he mentioned serendipity as contributing to scientific exploration:

I think some people do stumble upon stuff without, stumble upon discoveries without really having a very deductive, analytical mind, but I think in order to purposefully find out the answer to a question, I think you do need to be analytical.

Here he discussed the balance between logic or being "analytical" and serendipity, stressing the importance of logic over luck, but stated that both can contribute to science. Note at this point he also mentioned finding answers to questions as being fundamental to science. Toward the end of the year he discussed creativity as being important to science when I inquired about it, and stated, "You have to probe into the subject in roundabout ways that are creative." At this point he mentioned "intelligence" and "luck" again as well.

Although his conception regarding this premise was fully formed and remained mostly unchanged throughout the year, he did have some interesting comments about the balance between creativity and logic. I inquired if he thought most scientists were
men or women and he responded as follows:

Larry: I think that women are more emotional...yeah, more emotional to me and men are more logical and I think that...men and women explore (science) differently. Different areas men would be apt to explore than women. I think, this is what I am thinking now, I could be wrong, but I think generally science requires more logic than does more feelings and emotions. So, I would say not to a large extent, but men would be more scientific.

D: You said that science requires creativity. Do you think women are more creative?

Larry: I think the larger part of it is logic.

He again emphasized the importance of logic in science over creativity (although he felt both could contribute), and went on to state that he believed that men are indeed more logical and perhaps better suited for scientific work. This notion was confirmed through informal discussions in class as well. One possible reason for this belief is the ongoing teenage saga that unfolded between Larry and his girlfriend over the course of year. At the beginning of his junior year Larry entered into his first "serious" relationship with a fellow female student, and not surprisingly this occupied much of his time and thoughts. During times in which they experienced "problems" he often remarked how emotional and illogical his girlfriend was. I believe his new experiences with dating contributed to his beliefs about the balance between logic and other areas of science. He preferred strict logic over other areas that he had difficulty understanding.

"Scientific activity is a social activity conducted by individuals who are influenced by both cultural and personal factors" is the next premise of the model. Larry's understandings of science being influenced by society/culture evolved over the course of the year becoming fully formed. During the third interview he stated "the
desire to know" was what guided scientific work, but by the fifth interview explained "I think they come from the needs of society or the environment..." when discussing this area. He developed an understanding of the balance between an individual scientist's interests in working in a particular field and the societal pressures which often precisely dictate what a scientist will work on. I believe it was his tornado project which helped him develop this new understanding. He stated that interviewing a meteorologist helped him gain an understanding of what scientists do.

Additionally, when I asked Larry if he thought that science may be done differently in different countries around the world, he responded that it might because of the "different mind sets about life" different people may have. He cited the way different people consider personal property around the world because of their cultures.

He thought of scientists as humans. He believed that individual scientists might be influenced by their own personal experiences when doing science. He thought different scientists might have different perspectives on science because of who they were. His fully formed understandings of this aspect of the premise remained unchanged during the year. His overall conception of this premise was ultimately complete.

"Questioning, data collection and analysis, drawing of conclusions, and communication are the major phases which characterize the scientific endeavor" is the final premise of the model which deals with the nature of the scientific enterprise. Regarding this overall premise, Larry held a fully formed conception which did not evolve throughout the year. During the second interview he outlined what he believed
were the steps to the scientific method quite succinctly, "First you state the problem, form a hypothesis, experiment, collect data, analyze the data, and form a conclusion."

During the fourth interview I inquired if his projects from the previous semester, which were science related, actually followed the scientific method, and he responded:

In a way they have, the experimental part is mostly done by other people and I sort of look at what they have done, because...experimenting with tornadoes is (only done by) a major lab facility...

There are two important points to note regarding his response. The first relates to his notions of the definition of science which included "new knowledge." He recognized that his projects did not necessarily generate new knowledge, but that he was uncovering what other people have found. The second important point deals with the limitations of students' abilities in Project Seafarer to directly examine their science questions due to the choice of topic. Even if the research questions were framed in such a way that they were researchable, as will be discussed shortly, the choice of topics often made it impossible to examine them in a manner which fostered the collection and analysis of original data. In Larry's case, it clearly would be impossible for him to study actual tornadoes without traveling to an area where they occur or a laboratory which simulates them which is why his "research" was merely collecting information published elsewhere.

Larry understood the importance of questioning as a key aspect of the process of science from the very first interview:

D: What about questions? The notion of asking questions? How does that relate to science?
Larry: In every way it does. Without the questions you'd have no answers and the answers are what you base everything on. And
if you didn't ask the questions, you wouldn't have, if you didn't ask why or how a DNA strand replicates, if you didn't ask that and didn't wonder it and carry out the means of finding out how it does replicate...if someone didn't do that, we'd have no idea how...inquiring.

As stated earlier, he did not hold the belief that everything is science and he also understood that not all questions are scientific. For Larry, a question must be posed in such a way that it asks "why" or "how" and deals with scientific content in order for it to be a scientific question. He recognized that although questions guided both his science and literature projects, the literature-based questions were not scientific.

He found it more difficult to pose literature related questions, yet easier to present these projects, with the opposite being true for science related project work. For the literature projects, he derived the questions from the extensive readings he completed (mostly fictional novels). For the science projects, he was able to generate the questions prior to beginning the work based solely on his personal interests and knowledge. He viewed both of these types of questions as "essential questions," in which during the final interview of the year he defined as:

An essential question is just like one that has almost like a philosophical entity to it. It can't just be a cut and dry, yes and no. Like, is the weight of a penny larger than the weight of a dime? You know it can't be something that you have an exact yes or no answer. It has to be something that can be variable.

This notion of an essential question, as mentioned earlier, led to difficulties in one project in which he was pursuing a literature credit. He thought of an essential question as more of a guiding question than a researchable question, a question that orients one's work, but is not necessarily one that is easily answerable. As Larry put it, it has a "philosophical entity" to it. Because of the built-in vagueness to essential
questions he interpreted one very differently than his cooperating teacher and intern did. This led to the miscommunication, but it was ultimately resolved.

Like many students, Larry viewed data collection, analysis, and drawing of conclusions as being very closely related. As stated earlier he recognized that the information that he acquired from the internet or from other sources served as data collection for him, even though he knew scientists usually collect original data. During the second interview he defined data analysis as "sort of just compiling it, putting together a general idea of what it all means." He viewed the process by which one goes from essentially raw data, or information, to a conclusion as a continuous process of analysis and drawing of conclusions. His full understandings of these aspects of the premise remained unchanged over the year.

Regarding the communication of results, he mentioned that scientists "publish" results several times throughout the course of the year. He found his own presentations for Project Seafarer "nerve racking," but felt that he improved upon them as the year progressed. He enjoyed sharing his work with his peers prior to presenting it formally. The use of "critical friends" encouraged an informal sharing of ideas which he believed was valuable to all work.

The first premise dealing with the nature of scientific knowledge states, "Scientific knowledge demands evidence, and is testable through the scientific enterprise." Larry held a fully formed conception of this premise which remained unchanged over the course of the year. At several points throughout the year he discussed the concept of "proof" when making the judgement if knowledge is
scientific. He felt that experimentation was the primary means by which knowledge could be proven. Without proof, he felt knowledge is "nothing more than fluff and a meaningless statement."

The next premise states, "Scientific knowledge cannot provide complete answers to all questions." His understandings, which were once again fully formed and remained fixed over the course of the year, were closely related to the final premise of the model:

D: Can a scientific question be fully answered?
Larry: [pause] I think within any questions there are a multitude of questions that will branch off from that. You have this original question and it evokes another one, and they each do the same...

He believed that questions could not be fully answered and that they often lead to other questions.

The final premise of the model, "Scientific knowledge is tentative, developmental, and subject to revision" addresses this ephemeral nature of scientific knowledge. He summed up his beliefs about this premise when he stated during the final interview that scientific knowledge could be thought of as "common knowledge that we need to know before we can go on." Over the year he expressed full understandings of both the tentative and developmental nature of scientific knowledge as described in the final premise.

What was of particular interest about his understandings of these last two premises was his belief that human understandings of knowledge was what changed in many cases, not the knowledge itself. He stated it was "our beliefs about (the knowledge)" that evolved and that we may "understand it more, or our ideas about it
have changed" even though the essence of the knowledge may be the same. This solidifies his notions of science as a human endeavor, an enterprise in which we attempt to explain and understand our world.

Conceptions of the Project-based Class - Larry seemed to greatly enjoy his Seafarer experience. He was generally apt to working independently on his academic projects, and needed very little encouragement to focus on his projects during class time. Like many students, he spent the first several weeks of the year becoming familiar with the technology in the classroom, but by the middle of the first semester seemed quite comfortable working with the computers and associated peripherals. He liked the freedom to work on his own projects yet appreciated the input from the various teachers and interns, stating about half-way through the year:

I think the good thing about Seafarer is there are fewer guidelines than there are in a normal classroom and that's what I think Seafarer is all about. That it's a little freer. I think the things that guide it are...that our teacher-coaches and interns have given us things that they want us to do and also our personal agendas. Guidelines that we want to learn about...

He held this opinion of the need for a balance between input from the teachers and interns and his own ideas even after the miscommunication in the literature project. Reflecting on the year during our last interview he noted that it was a difficult class, "I think it is the hardest subject I have. I do the most work in it." However, it was clear that he preferred this way of learning, and discussed learning science in this project-based format:

Larry: There is no room to do your own exploring of what you want to in a regular science course [pause] this is what you learn, this is how you do it...but with a Seafarer project you formulate your own ways of learning, you create your own questions, that's truer
D: Has (Seafarer) made you think about science differently?
Larry: It has made it more interesting. You analyze more when you aren't told what to learn, you think for yourself...making your own effort to go out and discover whatever it is you want to discover.

Larry also held generally positive views about the boat building portion of the class. Although toward the end of the year he felt that there was too much emphasis placed on finishing the boat, he still had the desire to finish and launch the boat by the end of the school year. He was heavily involved with several extracurricular activities and when students were asked to put in extra "boat time" after school, he had to make a difficult choice in what to do, and only put in minimal extra boat time. During the class time he enjoyed working on the boat, and liked interacting with teachers, interns, and other students, which he thought was a nice change from independently working on his academic projects.

Part way into the second semester as the boat was being planked and really beginning to take physical shape, his interest in the boat became more heightened. He stated, "It's coming up to the point where you can see the boat form. You know...the planks are really going on and it's more exciting..." Like many other students in the class as the boat took shape, they became more dedicated to finishing it by the end of the year, although it was often difficult to put in the extra time needed to complete it. Although he was invited to participate in a similar project-based class next year at Woodland, he was elected editor of the yearbook and decided that he could not handle both. He decided not to sign up for another year of this project-based class, citing time constraints. He will continue to take science courses, and stated that there is a chance
that he might work in the field some day. The next sub-section will summarize Larry's conceptions of the nature of science during the year.

**Summary** - Larry held mostly fully formed conceptions of the nature of science over the course of the entire year. Regarding the first premise which states that the universe is open to human description and understanding through scientific exploration, he addressed the notion that humans have the *capacity* to explore and understand the universe in a way which is scientific, but may not necessarily ever come to know all there is to know. In addition, he did not consider "everything" to be science, and understood science as one way of thinking, exploring, and ultimately knowing.

His understandings of the second premise, which served as a definition for science, changed over the course of the year. These changes centered around Larry thinking of science in an applied manner. Most importantly, however, he understood that science can generate new questions while at the same time believing that science can explain and predict phenomena. He held unformed understandings of science comparing theories and checking on previous results.

Regarding the next premise, he often discussed the balance between logic and serendipity, stating that both contribute to science, but stressed the importance of logic over luck. He also discussed creativity as being important to science. His understandings of this premise remained unchanged throughout the year, although he did have some interesting comments about the balance between creativity and logic, and gender. His beliefs about gender and science highlight the importance of non-
science experiences that students may receive outside of formal schooling and their potential contribution to students' understandings of science.

Larry's conceptions of science as a social activity changed over the course of the year becoming fully formed. He developed an understanding of the balance between an individual scientist's interests in working in a particular field and the societal pressures which dictate what a scientist will work on. His fully formed conceptions concerning personal factors remained unchanged throughout the year. He viewed science as a human endeavor, believing that different scientists could pursue science differently.

Based on the overall premise which deals specifically with the scientific method, Larry held a full conception which did not evolve over the course of the year. He understood questions as being of paramount importance to science, and differentiated between science and non-science questions. He recognized that scientists usually collect original data, but that he did not have the opportunity to do that in his own projects. He viewed data collection, analysis, and drawing of conclusions as being closely related, and thought these steps led to making meaning out of information. He mentioned that scientists publish, however stated that it was difficult for him to present science-related information.

Finally, concerning the three premises which deal with the nature of scientific knowledge, he also held fully formed conceptions which remained unchanged over the course of the year. He described the necessity for "proof" for scientific knowledge, believed scientific questions could not be fully answered and often lead to other
questions, and understood the developmental, tentative nature of our understanding of knowledge itself.

Woodland Summary

Results from this study indicate that students' beliefs about the nature of science may not be as poor as outlined in previous studies (Lederman, 1992; Meichtry, 1993). It is important to note this was a year-long qualitative assessment of student conceptions, and this methodological approach may be a significant factor in uncovering students' knowledge about the nature of science, explaining the apparent inconsistencies in findings.

By the end of the year, participants at Woodland exhibited fully formed conceptions of the nature of science approximately 40 percent of the time based on the premises of the model developed and utilized for this study. However, they held full understandings of various aspects of those premises approximately two-thirds of the time, even if their overall conception of a premise was partially conceived. In three-quarters of the cases, whether fully or partially formed, students' conceptions were unchanging over the entire school year.

Regarding the first premise which states that the universe is open to scientific exploration and understanding by humans, all participants held partially formed conceptions which remained unchanged over the course of the year, except for Larry who held fully formed, unchanging conceptions. Larry understood science as merely one way of exploring the universe. Ben, Bryan, and Donna held the belief that
"everything is science." These students viewed science as an organized, systematic process of "finding out how things work," and considered almost any ordered activity "scientific" in nature.

All participants held partially formed conceptions of the second premise which describes science as explaining and predicting phenomena, comparing theories, checking on results, and generating new questions. Larry was the only participant to fully understanding that one aspect of science is generating new questions.

Larry and Donna held fully formed conceptions based on the third premise which deals with logic, imagination, curiosity, and serendipity. Linda developed a full conception of this premise throughout the year. Most participants believed logic or intelligence were more crucial to the scientific enterprise than imagination or creativity. Larry believed that men were more logical than women and would make better scientists. Neither Ben nor Bryan addressed the role of serendipity in science.

Although all participants, except Linda, understood science as a social activity, only Larry and Bryan held fully formed understandings of science as an activity influenced by personal factors, describing science as a truly human endeavor.

All the participants held partial conceptions of the next premise which states questioning, data collection and analysis, drawing of conclusions, and communication characterize the scientific enterprise, except for Larry who held a fully formed conception. Many students noted that they had not gone over the steps of the scientific method in years. It was not made explicit for Linda that she experienced the "steps" when completing her first project. Most participants made use of questions to guide
their project-based work, however Donna found them limiting and based her research on themes or topics.

Regarding the first premise which addresses the nature of scientific knowledge, and states that this knowledge demands evidence and is testable via the scientific enterprise, most participants' beliefs were fully formed and unchanged. Only Ben held a partial conception. Most students consistently emphasized the notion of "proof" as being required for knowledge to be considered scientific in nature.

Only Linda held a partially conceived conception regarding the next premise which states scientific questions can not be fully answered. Ben, Bryan, and Larry's understandings were fully formed. There was insufficient data to describe Donna's beliefs based on this premise.

Finally, both Bryan and Donna held partially formed conceptions regarding the last premise which states that scientific knowledge is developmental, and tentative in nature. The other participants held fully formed, unchanging conceptions over the course of the year.

Themes

There are several predominant themes which have arisen from the work at Woodland. These important points will be briefly summarized here and discussed in detail in Chapter VI. However, it is important to note that I believe the strongest aspect of this body of work lies within the richness of the descriptions themselves. Reviewing the student conceptions of the nature of science, often in participants' own
words, can best provide the reader with insight into what students' believe.

This first notable point was mentioned at the beginning of this summary section and deals with the qualitative nature of this study. To date, a considerable amount of research with the focus of examining student or teacher conceptions of the nature of science has been strictly quantitatively oriented (Lederman, 1992). As described in Chapter II, these studies have made use of several instruments developed to assess various aspects of the nature of science. In some recent cases, such as in Abd-El-Khalick and BouJaoude (1997) participants were interviewed following the implementation of a questionnaire.

In contrast, this study was not only qualitative in nature, making use of formal interviews, participant observation, and student work, but was relatively long-term as well. The focus of this study was to describe student conceptions of the nature of science over an entire school year. Frequent contact with participants, both formally through interviews and informally in the classroom setting, has enabled me to more fully characterize their beliefs than might be accomplished through a short duration, often one-time quantitative study. In fact, many times it would have been impossible to describe participant beliefs at all without the benefit of both interacting with them during school and more formally speaking with them about their conceptions.

Another significant point is the participants' beliefs that "everything is science." Three of the students at Woodland held similar conceptions in which they may have extended the organized, systematic nature of the scientific enterprise to believe that any ordered process "has a science to it." As a result, in one case even ordering lunch
was described as being science. Similarly, although all participants believed the universe was open to description and classification through science, it was Larry who most adequately discussed science as a way of knowing which differs from other ways of knowing. He was able to provide an example and a non-example of science, describing his spiritual beliefs and understandings as differing from his scientific ones. Perhaps the use of non-examples in science to teach certain concepts (Trowbridge and Mintzes, 1985) may be utilized to teach about the nature of science itself.

Another important finding centers around the use of questions in project-based work. Some participants found questions limiting, while others believed they needed them to conduct their research. For the most part, students at Woodland generally thought of research as collecting and compiling information, not as gathering original data. Even when Linda collected original data, it was not made explicit that she was participating in an important aspect of the nature of science. Although most students made use of questions to guide their work, others did not. For example, Donna chose the topic of AIDS and collected her information and retro-fitted a question to her project for evaluation purposes only. She knew she had to have an "answer" to a question when she presented her work. This "after the fact question" was pointless. An important aspect to both project-based work (Katz, 1994) and the process of science (AAAS, 1989; 1993) are questions. In addition, when participants did make use of questions, in most cases they were not "researchable" questions as described in Moss, Abrams, and Robb Kull (in press). Participants described these questions as "essential questions" but were unclear on exactly what that meant. In many cases, participants...
were unsure if their questions were too broad or too narrow for use in their projects, and were concerned if they were at all appropriate.

Finally, when conceptual change was observed in participants, it was sometimes difficult to determine the cause of this change. Were participants dissatisfied with their current model of thinking? Did they merely pick up on an interesting idea they heard in class and incorporate it into their thinking? When change was observed it was not usually holistic but incomplete as described in Southerland (1997).

It is also important to note that experiences students received outside of formal schooling may have had an impact on their beliefs. Several participants watched television and read magazines which dealt with scientific themes. These experiences need to be considered when examining their beliefs about science, however in many cases it seems participants' conceptions were not easily altered by any means.
CHAPTER V

VALLEY HIGH SCHOOL

The Setting

Valley High School is a semi-rural New England public school which serves approximately 800 students grades 9 - 12. This school prides itself on being a non-traditional place of learning. Many students and teachers spoke well of this school, remarking how lucky they were to work at or attend Valley, and the overarching feeling there was a positive one. There is tremendous support from the community, both in terms of financial resources and parental involvement. Perhaps due to such strong support, there was a feeling of school pride by many students and teachers that permeated much of what transpired at Valley.

As one walks down the bright and well maintained halls of Valley, one often sees students working in small groups tucked away in the corners where lockers and benches reside. Located near the front entrance to the school is a carpeted "pit" in which students come to socialize, play music, and on occasion discuss school work. There is an openness to this school. That is, students seem to have more liberty throughout the day to interact with each other and teachers than in many high schools. Although a daily class schedule is followed, students have the freedom to move about the school during free periods in pursuit of school-related activities, and are generally encouraged to take responsibility to accomplish what they need to do during the school day.
Teachers have divisional offices where they each have a desk, use of a phone, computer, and copier, along with a place to meet and eat lunch. Students often dropped by these office suites to leave a teacher a note, discuss a problem, or leave some work. For the most part, teachers are very accessible to their students outside of class. Learning happens both inside and outside of the classroom environment at Valley.

The school building itself is relatively new, only being several years old at the outset of this study. The facilities at this school are excellent. From the rock climbing wall to the information center, more commonly known as a library, students have many resources at their disposal. The information center, appropriately located in the center of the school, contains networked computers for on-line communication and research, in addition to the periodicals and books available for check out. Many students were seen interacting and working in this facility throughout much of the day. Although it was sometimes noisy, it was because it was a busy, active place where students worked. Along with computers in the information center, there are several technology rooms which contain 20 or more computers, each networked to a main server. These technology centers are in addition to the several computers located in each classroom throughout the school. Students and teachers have accounts which allow them access to the computer system from almost any point in the school.

There are no bells to disrupt the school day at Valley, teachers and students moved smoothly from class to class at the appropriate time. Rarely did teachers need to usher students on to their next class. There were short breaks scheduled throughout
the day in which students might drop by the school store for a soda, or check their
computer account for messages. Although occasionally students wandered into class
late, for the most part they followed the daily schedule. The hallway remained
relatively clean as did the classrooms. Students respected the building itself along with
the rules in place that governed it. As a result, they had use of many resources
throughout their day, including those available in the science classrooms.

**Conservation Biology Environment**

The Conservation Biology classroom was located on the second floor of the
building. This large room, which contained tables arranged in a square in the center of
the room, served dual roles as a laboratory and regular classroom. The tables seated
the 20 students in class with plenty of space to move about the room as needed. The
counters and shelves which lined the walls stored scientific equipment, such as
microscopes, and served as home for the several resident snakes. Other resources in
the Conservation Biology classroom included a drying oven, field equipment for
collecting data in forestry and fresh-water settings, resource books, computers, a TV
and VCR, and examples of student work such as posters and papers produced by
students in past years. At several points during the year the class met in an adjacent
room to the usual classroom to allow another class to make use of the laboratory
capabilities of the room, however this alternative classroom still had tables clustered
throughout the room facilitating student interaction and group work.

In addition to the science classrooms, the Conservation Biology class also made
use of the technology classrooms located on the first floor. At several points throughout the year when all of the students used the computers during class time, such as for graphing of data or scientific modelling of population dynamics, the class would meet in one of these technology rooms. There were enough computers for each student to work individually as well as a computer outfitted with projection capabilities located in the front of the room. The student computers were housed on small tables which accommodated three students in such a way that student to student interaction was facilitated. In addition, large work tables stood in the center of the room.

The class also had access to several field sites within a few minutes of the school that were utilized for various projects. A small river ran nearby the school which served as a place for study and data collection at the beginning of the year for a project that researched river health. This river also served as a backdrop for a salmon restoration project later in the year. Not far from the bank of the river was a mixed softwood/hardwood forest containing beech, birch, and pine trees. This forested site served as a permanent data collection plot for a project on forest health. The river and forestry projects comprised the bulk of the school year for this project-based Conservation Biology class. The underlying philosophy and curriculum design for this course is discussed in the next section.

**Project-based Philosophy and Curriculum Design**

As one enters Valley High School one can immediately begin to understand the
philosophy of this non-traditional school. The essence of the school's philosophy is cast in bronze in the front entrance of the school. The underlying philosophy of Valley incorporates such notions as respect, trust, and courage, along with the empowerment of students. This mission statement encourages students to push the limits of their own knowledge while taking responsibility for the stewardship of the globe. Valuing each individual's contributions to the learning community at Valley is also stressed.

Being a new building, the school was in a very real way "built" upon the schools' beliefs. For example, the use of traditional testing is minimized. Much of the grading is accomplished through the use of rubrics in which students demonstrate their learning through oral presentations or written work. In order for students to graduate from Valley, they must propose, complete, and present a senior project. This intensive year-long effort occupies a significant amount of time during a student's senior year. Although they have great latitude in the choice of a topic to pursue, they must explore that topic in such a way that they generate new knowledge, and justify the significance of their work. Like much of the school work at Valley, both the product and process of learning are stressed. Students are evaluated at various stages throughout their project, culminating in a final formal presentation in front of a panel of faculty. The senior project is taken very seriously by all members of the school community, and requires a significant amount of time by both teachers and students. Students are expected to demonstrate a high quality of dedication and work throughout their project, however, many students commented over the course of the year that demonstrating quality project-based work was the norm for many of their classes as
well. Students remarked that they believed much of their course work was designed to eventually aid them with completing their senior project.

The Conservation Biology class itself, also considered non-traditional by many schools' norms, was only one of several project-based science classes offered at this school designed to explore the sciences in an integrated, holistic manner. All science classes, including this one, follow a curriculum philosophy which is outlined in the Valley High Science Curriculum Framework (see Appendix D). Part I of that Framework in part reads, "All students need to be scientifically literate and active contributors of new knowledge to our local and global communities." Their definition of scientific literacy is adapted from Project 2061 (AAAS, 1989; 1993), and includes such notions as real-world problem solving. In fact, their Science Curriculum Framework prescribes that students contribute to new knowledge through "active student inquiry." As a result, the Conservation Biology class completes several major projects which are designed to facilitate the collection and exploration of original scientific data.

The year started with the investigation of the health of a local river, and that project lasted through mid-January. Like all projects, this project was directed by Daria, the teacher, and the students pursued the project as a class. Although at various points students may have divided up the work load for efficiency sake, the class essentially worked on the same aspects of each project as a single unit. The students began the year exploring the physical aspects of the river. The rate of water flow through various points in the river and erosional features were examined by making
measurements at the river and through the development of models. Next, the chemical properties of the river were tested. Dissolved oxygen, pH, and other parameters were studied by collecting samples of river water and performing various tests. Finally, macroinvertebrates were examined with regard to their relationship to river health. The absence or presence of certain species can indicate the health of a river. This data is sent to an environmental agency which monitors New England watersheds. Over 50 schools participate in this program.

The next project was a salmon restoration project. This class project entailed studying the life cycle of the Atlantic salmon which included raising salmon from eggs to a young adult stage when they could be released into the local river. This project also encouraged students to examine historical reasons for the decline of salmon in New England waterways. Environmental, cultural, and political reasons were investigated. As part of this project, representatives from the Fish and Game Service visited the class and reported what they did for work as scientists for this federal agency.

Following the salmon project was a computer-based population dynamics modeling project. This short project, which only lasted several weeks, gave students the opportunity to break into small groups and investigate an animal species of their choice. Although each group investigated a different animal, the procedure of completing the project was the same for each group. They began by collecting information on the birth and death rates of the animal and entered those numbers into a computer program which modelled, or estimated, a population growth curve for each
species. Students considered human interaction with the species, such as hunting, and modeled changes in the population over a given time frame.

The final project of the year which lasted from March through June investigated the health of a terrestrial ecosystem, specifically white pine forests of New England. This project began with the use of Earth-orbiting satellite images to explore land use patterns of the area local to the school. Daria felt this portion of the project required extensive background information for the students, and a great deal of classroom time was spent examining the underlying principles of satellite-based monitoring of the Earth. Next, students visited the permanently marked white pine plot adjacent to the school and learned field techniques to quantify various parameters of the forest, including measurements of tree height and diameter along with estimations of the amount of living needles on the tree and ground cover growing on the forest floor. Collections of white pine needles were then made for study in the laboratory. The amount of water in the foliage by weight, needle length, and the presence or absence of damage symptoms were just a few of the measurements conducted by students following the collection of needle samples. In addition to the collection of samples for study by students, the class collected a duplicate set of needles which were sent off to UNH for examination. Valley High was one of over 60 schools in New England who were part of an environmental monitoring project titled Forest Watch. Participation in this project encouraged classes to contribute to an ongoing scientific study at UNH while at the same time experiencing some of the activities that scientists at the university actually do as part of their own research.
The river health project, salmon restoration work, and Forest Watch project were all projects designed to foster partnerships between the Conservation Biology class at Valley and scientists working in various fields. As discussed in Moss, Abrams, and Robb Kull (in press) these student-scientist partnerships (SSPs) were designed to foster the exploration of "real world" science by students. This authentic student inquiry, which was specifically mandated in the Science Curriculum Frameworks for Valley, was the underlying philosophy which drove this class. Students were expected to participate in many aspects of real scientific inquiry throughout the completion of these projects. The next section will discuss typical activities in which students participated over the course of the year.

A Typical Day

I would arrive at Valley a few minutes past seven, prior to the beginning of the school day. This early arrival allowed me some time to go over a few observation notes from my previous visits, and check in with Daria to see how the week was going and what was happening that day. The Conservation Biology class met for five 50 minute class periods each week, with the day that I visited usually being the one day each week that the class met for two back-to-back periods. At about 7:30 the principal would announce over the school intercom system that school was beginning in a few minutes, and would make a few morning announcements about school activities for the day while students made their way to class.

The bulk of the Conservation Biology classes were reserved for students to
work on various aspects of their class projects. For example, in the beginning of the year they spent a week building physical models of the river bed in order to study water flow through the river. Toward the end of the year, class time was reserved for making measurements pertaining to the Forest Watch project. During these periods, students worked either from handouts which described the activities underway or from directions conveyed by Daria at the beginning of each class. It is important to note that most students in the class were working on the same aspects of each project at the same time. If the day was reserved for measuring needle length, then that's what students did.

In addition to teacher-directed project related work, class time was also utilized for direct teacher to student instruction. Quite often this was accomplished through lecture format in which Daria conveyed information to students with help from prepared overheads or white board work. This information transfer was usually done at the beginning of each segment of a project when Daria felt that students needed an orientation to the activities for that portion of the project. Frequently this instruction centered around data collection activities that students would be conducting. Daria would review accepted protocols for collecting accurate data while demonstrating various pieces of scientific equipment. She also lectured about data analysis. Once students had collected all of their data she would provide examples of how to organize and examine that information. Following these lectures, students would either collect or analyze their data depending on where the class was in the project. Daria also made use of lecture format to convey background information to students, such as when
students began the satellite monitoring portion of the Forest Watch project.

Students, in small groups or individually, would also make use of class time to work with technology for graphing or modeling purposes. On occasion, students would spend time in the information center to collect information about a project. At several points throughout the year students were required to make presentations in class. Although these will be discussed in greater detail later, these presentations did afford them the opportunity to share information with their fellow students in a more formal setting than just the usual interacting in class. Generally, whatever the activity for the day, the class was run very informally which encouraged students to discuss whatever work they were doing at that time.

There were several occasions in which the class headed outdoors. For the river project, students collected samples of water and waded through the river measuring such parameters as temperature and depth. For the Forest Watch project it meant a short walk to the forested site where students made various measurements pertaining to the pine trees at that site. During most of these data collection field trips, Daria would review the collection protocols before allowing students to make their measurements. However, once these measurements were made a few times she would allow the students who needed to make additional measurements to visit these sites and conduct their data collection without teacher supervision. In most cases, students were aware of the need for precision and accuracy when collecting these data sets. Students very much looked forward to these days in which they could spend some time away from school, and as one student put it, "play outside."
Although students were excited about making data collection trips because they were outdoors, they took these field trips very seriously. In fact, they took the entire class seriously, but enjoyed it as well. The next section will describe student experiences in this class while discussing their understandings of the nature of science over the course of the year.

**Meet the Students**

**Heather**

Describing herself as a "science person," Heather was looking forward to someday working in the environmental conservation field. Although she wasn't sure if college was in the immediate future for her after high school, she was a junior during the course of this study and had some time to make her decision. She was an average student based on her academic achievement. She thought that the Americorps or some international volunteer program might enable her to work in the rain forests and it would be a fun, productive way to spend a few years after she graduated from Valley.

Heather had transferred into the Valley district after her ninth grade year in which she completed biology at a neighboring school district. During tenth grade she enrolled in chemistry, and this year Conservation Biology was her only science class. She had the option of taking physics instead of Conservation Biology, but at the beginning of the year remarked that she thought that this class would be more hands-on and fun. Daria, the Conservation Biology teacher, enjoyed an excellent reputation at Valley and her classes were well known for being active and interesting. Although
Heather wasn't sure what the class exactly entailed, she hoped that it would help her decide if this was indeed an area in which she would someday pursue.

Regarding Heather's conceptions of the nature of science, as with all the participants in this study, I will address them in relation to the premises of the model. The first premise of the model states, "The universe is open to human description, classification, and understanding through scientific exploration." As with all participants, Heather essentially took for granted that science enables humans to describe and classify our universe. Her understandings of this aspect of the premise were unchanging and complete.

Heather did not hold the belief that "everything is science." She thought of science as a separate endeavor that one could choose to participate in or not. She thought science was science, and other disciplines were separate even though she often had difficulty explaining exactly what those differences were. I believe to her it seemed cut and dry and did not warrant a detailed discussion. Although she did not believe "everything is science," at no point during the year did she specifically discuss other ways of knowing besides science when it came to understanding our universe. Her conception regarding the overall premise was therefore incomplete. Her beliefs did not evolve over the course of the year.

The second premise, which served as a definition for science, states, "This scientific exploration attempts to explain and predict phenomena, compare theories, check on previous results, and generate new questions." During the first interview, Heather had some difficulty defining science when I asked her to:
D: Can you define science?

Later in that first interview she reiterated her point about nature when she said, "Anything that has to do with nature is science." During the second interview she also mentioned nature as being central to her notion of science. When I asked her if there was something unique about science that in a sense defined it as science, she responded, "Science is the study of [pause] hmm [pause] relationships with nature and life. I guess chemistry also." Although she expanded her definition to include the notion of relationships and added chemistry as a component to her definition, nature was still at the center of her beliefs. Heather's definition was similar during the third interview in which she stated, "I think science is just the study of nature. Like how things work." Here we again see the familiar phrase "how things work" which many students have used to characterize science.

By the fourth interview, Heather still seemed unsure as to her response to my question in which I asked her to define science, she stated, "Science is the study of the environment, nature, physics, um [pause] I don't know, the world." Although here her definition still included nature, it also identified both a narrower area of focus, "physics," and a broader area, "the world." During our fifth interview, our conversation went as follows:

D: The first question is just define science.
Heather: Science is the study of how things work.
D: Is there a common goal do you think to all of science?
Heather: I guess to discover like to find answers to questions that like already exist or problems.
Although her understandings of science changed somewhat over the course of the year, it was not until the fifth interview that the most significant change in her responses to my inquiries occurred. She did not specifically limit her definition to nature, nor any other area, and folded the notions of questions and problems in as well. Heather had the opportunity to choose her own question for investigation to conclude the salmon restoration project. She investigated whether Atlantic salmon should be placed on the endangered species list, and perhaps that experience helped foster this change. As will be discussed later, she viewed questions as important to the process of science, so by the end of the year perhaps it is not surprising that she eventually included this notion into her overall understanding of science.

Several times throughout the year she mentioned "theories" when discussing science. At one point when she characterized science during the first interview, she stated, "It was working toward developing a theory." Later in the year she defined a theory as "a hypothesis that has been tested again and again." She noted that a theory could potentially lead to a "fact" if, like a hypothesis to a theory, it was tested. She viewed hypotheses, theories, and ultimately scientific facts as existing on a continuum based on the amount of evidence there is to support each level of knowledge.

Heather understood that science could explain phenomena while testing theories. She thought this might also include revisiting previous results. Although she came to understand the important role questions play in science, she did not specifically state that the process of science generates new questions. In addition, she did not address the notion of "prediction." Although her beliefs evolved regarding this
premise, her overall conception was only partially formed by the end of the year.

The third premise of the model states, "Logic, imagination, curiosity, and serendipity contribute to scientific exploration." Heather often described logic, or intelligence, and curiosity as being closely related and important to the scientific enterprise. Toward the end of the year she stated, "I think that curiosity and like wanting to learn things is characteristic of a smart person." She also stressed the importance of creativity and imagination, although she never specifically mentioned serendipity or luck as contributing to science. Her unchanging conception relating to this premise was therefore only partially conceived.

"Scientific activity is a social activity conducted by individuals who are influenced by both cultural and personal factors" is the next premise. Regarding science as a social activity influenced by society/culture, Heather's understandings were unchanging and fully formed. During the third interview she identified both "need" and "problem solving" in addition to scientists working in areas that are of interest to them as guiding what they do from day to day:

D: How do (scientists) know what to do? Like what guides what they do every day?
Heather: I would say just a question that hasn't been answered or that has been answered and they'd like to further investigate...
D: Where do you think scientific investigations come from?
Heather: I think that most of them come from a need for an answer to a certain question and then there are some that are just you know for curiosity...but usually there's a problem first.

Heather also cited the government, medical facilities, schools, and organizations as supporting scientists in their work.

Based on the other area of this premise which states that scientists are
influenced by personal factors, Heather's understandings were again fully formed and consistent over the course of the year. As mentioned earlier, about mid-way through the year during the salmon restoration project, two representatives from the Fish and Game Service visited the Conservation Biology class to discuss their own salmon restoration work. Unfortunately, these two individuals were less than lively, and the students found them "boring" and "weird." However, it was obvious that they were dedicated to the restoration of salmon in New England waterways, and they made their personal opinions quite clear on this matter in addition to outlining the work they did on the overall project. It was difficult to tell where their personal views ended and their work began. I was curious if Heather picked up on that, and our conversation unfolded as follows:

D: Do you think scientists have opinions?
Heather: Yeah.
D: What about those two guys who came in from the fishery?
Heather: Yeah.
D: Did you view them as scientists?
Heather: Yeah I did. Not like lab coat chemistry scientists, but yeah, they were involved in nature and conservation...
D: Do you think they were, when they presented to you, did you think they were presenting sort of science based on facts or science opinion or-?
Heather: They were, they had a lot of facts. They had a lot of facts but they also did have an opinion which was that obviously they were for (salmon restoration), they're... talking about the benefits about what they were doing.
D: And you think it's ok that they had opinions?
Heather: Yeah.
D: Or should they have just stuck to the facts?
Heather: No, it's ok to have opinions. I mean, it was their belief that they're helping out and if they can influence other people to change their ways or do something to help out, then they're going to do that. It makes sense.
Heather recognized that these two individuals were clearly influenced by their personal beliefs regarding this project, but felt that it was acceptable for scientists in general to not only have opinions but express them if they want to get a point across.

During the fifth interview I asked Heather if she thought that if two scientists conducted the same research would they get the same results, and she responded, "They won't necessarily have the same conclusion. Like they might both look at it and see something different." She held this belief over the course of the year never citing external factors such as technology as contributing to scientists reaching differing conclusions. She believed that it could be the scientist herself or himself who might be responsible.

The final premise of the model about the nature of the scientific enterprise states, "Questioning, data collection and analysis, drawing of conclusions, and communication are the major phases which characterize the scientific endeavor." Even though Heather stated numerous times throughout the year that "I can't list them perfectly," in fact she could list the steps of the scientific method. Her descriptions which were consistent and fully formed over the course of the year included questions, hypotheses, experimentation, data collection, data analysis, conclusion, and communication. At one point she even mentioned "title" as one phase but corrected herself and noted that she might be confusing the scientific method with the set up of a lab report.

At the beginning of the year when I inquired if she remembered ever making use of these steps at any point during her school career she cited work she did for a
science fair in ninth grade. At the end of the year she answered the same question by stating that the projects she did in Conservation Biology certainly seemed to make use of the steps.

Regarding the questioning phase of scientific research, Heather believed that questions were essential to science from the very first interview, in which our conversation went as follows:

D: What do you think they do, scientists?
Heather: Um, they take a question and some sort of hypothesis and they try and figure out if it's right or wrong or answer a question.
D: Exactly, what's the relationship between a question and science?
Heather: Um, I guess in order to learn more about science I guess you have to question just about everything. Hmm [pause]
D: Are there questions that aren't science?
Heather: Um [pause] I think so, I wish I could give you an example. Um [pause] yeah there is basic yes or no questions that aren't science...

At this point she went on to describe science-related questions as those which deal with examining theories. She summed up her beliefs about questions and their role in science when I asked her if one could do science without a question, and she responded, "Um, yeah you could do science, but it...would just be fooling around with science." Throughout all the interviews, questions and questioning were prominent in our discussions regarding science, and Heather clearly believed that questions were a key element to the process of science.

Heather noted that in class sometimes they were encouraged to come up with their own questions during and after a project, but that they only "discussed them with the class, we didn't go out and test them." Concerning the questions that the class actually investigated, she noted, "They don't really come from me, no. I'd say that..."
they've kind of been supplied for us..." When I inquired about the questions which
guided the first class project, the watershed project, Heather seemed frustrated that she
could not remember what they were. When she could not state them for me she said,
"Um [pause] I know there are! We have two essential questions that we are working
on right now for this project that we are doing."

Heather referred to these questions as essential questions, and I asked her to
define that for me:

D: What do you mean by essential questions?
Heather: When we are done with the unit this is what we should have
answered or this is what we are trying to answer. I wish I could
remember. One of them has to do with the functional feeding
groups of the animal and a bunch of little questions.

At the end of the year, Heather also had difficulty describing the question which
guided the Forest Watch project, stating that "I don't know what the essential question
is." However, for all the projects throughout the year, although she may not have been
able to list the exact question guiding each project, she was aware of the major theme
which captured the essence of each project. For example, she knew that the Forest
Watch project had something to do with the health of the forest even though she could
not state the essential question. Considering how important Heather thought questions
were to science, it was surprising that she did not know them regarding her own
project work. However, since they were provided for her and her classmates, perhaps
she did not have ownership over them. She clearly did not need them to complete the
project work.

Heather viewed the steps of data collection, analysis, and drawing of
conclusions as closely related, yet distinct. She noted during the second interview, "The data is just numbers that we got, but when we compare them to each other, when different groups compare data...I consider that analysis..." During the final interview of the year, she mentioned that data analysis led to conclusions and was guided by the question "What does this mean?" Throughout the year she noted that accuracy was important in data collection and said that the class was as accurate as they could have been. However, she went on to state that with better "tools" for data collection the class may have been even more accurate. Although she felt that the class was involved in all of these steps, accuracy during data collection was stressed.

Regarding the communication of results, Heather noted that scientists write for journals or magazines and that they often present their results. She also noted that she had the opportunity to write papers for this class and make presentations, both of which she enjoyed. She especially liked the "reflective writing" that she was able to do for the class and that the writing was not too "lab reporty" which she enjoyed. She commented during the last interview that most of the scientific communication came at the end of each project. She felt that presenting science-related material was no different than the many presentations she had done for other classes. She described it as "mostly fact with a little bit of opinion."

I would characterize most of the class periods in Conservation Biology as being an opportunity for these students to informally share ideas about the projects that they were working on. Heather enjoyed the opportunity to work with her peers in class, and found this style of learning effective.
The first premise of the model of the nature of science which deals with the nature of scientific knowledge is "Scientific knowledge demands evidence, and is testable through the scientific enterprise." Heather's conceptions were once again fully formed and remained unchanged over the course of the year. She often discussed "proof" and the need for understanding the "how" behind things in order for it to be considered scientific knowledge. She also had a basic understanding of the notion of falsifiability. At two points in the year, once in the beginning and once at the end, she discussed hypotheses and theories and how sometimes they can temporarily be accepted because "no one can prove them wrong." She believed that experimentation and testing could go both ways in science, proving and disproving knowledge.

The next premise states, "Scientific knowledge cannot provide complete answers to all questions." Although her conception was uniform throughout the year concerning this premise, it was incomplete. During the third and final interviews of the year she stated that scientific questions could be fully answered, and during the final interview went on to comment, "otherwise there'd be no point." She did not ever address that many times scientific investigations leave more questions than answers.

Regarding the final premise, "Scientific knowledge is tentative, developmental, and subject to revision," Heather's conception was only partially formed and remained unchanged over the course of the year. During the beginning of the year she stated that one use of older scientific knowledge was that it might "enable (scientists) to go further with it, or might spark something in another person." This understanding of the developmental nature of knowledge was fully formed throughout the year. However,
she did not believe in the tentative nature of most knowledge. She stated that some knowledge might be subject to revision, referring to hypotheses or theories, but that most of it is not because it is already "fact." Once knowledge was considered to be fact, she thought it was likely to remain that way. This incomplete understanding was also consistent over the year.

The next sub-section will briefly discuss Heather's opinions of the project-based Conservation Biology class itself, and the following sub-section will summarize her conceptions of the nature of science.

Conceptions of the Project-based Class - Heather enjoyed this class very much, finding much of the course work relevant. Regarding the overall class, she stated:

Yeah, I actually really enjoyed this class. I usually enjoy my science classes. I think I can tell I really absorbed a lot of it, because sometimes like in math and stuff I learn stuff and it's just gone the next year. And I guess since it's science I can relate it to a lot of things, like outside school or I'll see something and I understand it...

She particularly liked the salmon restoration project in which she was able to choose a topic related to the theme of salmon restoration and write about it. She investigated whether the atlantic salmon should be on the endangered species list, and was able to put her opinion as well as factual information into her writings supporting the placement of this species on the list. She commented, "I guess I liked being able to put my opinion which was something we got to do with this project...and like we were making a difference." She also enjoyed the "human factor" of this project and was given the opportunity to investigate political as well as scientific aspects of this issue. She liked the watershed project as well but stated that she preferred the follow-up
laboratory work to visiting the river, which was opposite of most students.

She did, however, enjoy all aspects of the Forest Watch project, including the visits to the forest sampling plot. She commented that she really learned a lot, "because we did it ourselves, like we tested things." She said she learned a lot about the use of satellites to monitor the environment of the Earth, and explained:

I think part of the reason that I liked it so much is because I knew nothing about it. I had seen it before but I did not understand it at all when we started. And I did not think I was going to. Like when (Daria) first showed it to us, I was just like uh-oh, this is where my grade is going to start to fall. But I've picked it up. It was neat because I never really understood satellites and things like that and now I just do. And I can talk about it to my parents and stuff and feel smart.

As stated earlier, several of the projects for this class were projects in which various schools worked together with scientists in a student-scientist partnership (SSP). This seemed to make the projects "more real" for Heather. She noted:

Those ones kind of are more real because we're actually kind of changing something or it's actually going down on paper...our results are actually being used for the tree sampling project and the salmon, we're actually putting salmon into the river, so they seem a little more real.

This class certainly served to support Heather's budding interest in the conservation field. During the final interview of the year, she stated, "Environmental science is definitely something I could think about."

Summary - Heather believed that science enables humans to describe and classify our universe, but did not discuss other ways of knowing besides science. However, she did not hold the belief that "everything is science."

Heather's understandings of science relating to the second premise evolved somewhat over the course of the year resulting in her expanding her definition of
science to consider the role of questions and problems. However, she did not state that the process of science generates new questions or deals with prediction. In most cases, Heather's understandings did not evolve over the course of this study.

Heather stressed the importance of logic, imagination, and curiosity in science, although she never specifically mentioned serendipity or luck. Concerning the role of culture/society in science, she identified societal "needs" as guiding the scientific enterprise. Regarding personal factors influencing science, Heather felt that it was acceptable for scientists to not only have opinions but express them if they want to get a certain point across. She believed that scientists could indeed be influenced by personal factors when forming their ideas.

Even though Heather stated numerous times that she couldn't list the steps of the scientific method, in fact she could. Her consistent and fully formed descriptions of the scientific steps included such notions as questions, hypotheses, experimentation, data collection, data analysis, conclusions, and communication. Throughout all the interviews questions and questioning were prominent in our discussions about science. Heather commented that in her Conservation Biology class they were sometimes encouraged to come up with their own questions during and after a project. Concerning the questions that the class actually investigated, she noted that they were supplied for the class. She had difficulty articulating these essential questions, but knew the overall theme which guided each project.

Heather viewed the steps of data collection, analysis, and drawing of conclusions as closely related, yet distinct. Throughout the year she noted that
accuracy was important in data collection and said that the class was as accurate as they could have been given their equipment. However, she went on to state that with better technology data collection would be even more accurate.

Heather had a fully formed conception that scientific knowledge demands evidence and is testable through the scientific enterprise. She also understood the notion of falsifiability. She believed that experimentation and testing could go both ways in science, proving and disproving knowledge. She believed scientific questions could be fully answered, and noted there would be no point otherwise. Heather did not describe scientific knowledge as being tentative, and thought of this knowledge as mostly unchanging "fact." Once it was fact, she thought it was likely to remain that way. She did, however, believe that knowledge was developmental in that older research could spur on new ideas for study.

Dorothy

Unlike Heather who described herself as a science person, Dorothy stated right from the first interview, "I'm not much of a science person," but believed she needed to have four years of science on her Valley transcript to be more competitive for admission to college. She was an excellent student based on her academic achievement, but noted that science was usually her lowest grade. She had previously enrolled in Foundations I, II, and III her freshman, sophomore, and junior years respectively. She selected these integrated science courses over chemistry and physics for the same reason she had chosen Conservation Biology for this, her senior year.
Like the foundations courses, she believed Conservation Biology would cover more of a "broad range" of topics, as opposed to what she described she thought chemistry might be, which was "a lot more like in depth...one solid thing that you are looking at, formulas and calculations."

Dorothy was a popular student at Valley, athletic and involved in many extracurricular activities. Since she was a senior, she was required to complete a senior project in order to graduate. Her project was in the area of fashion. She ultimately coordinated and produced a fashion show and donated the profits to a local charity. She handled all aspects of this elaborate endeavor and hoped to be an event planner in which she envisioned herself producing large scale concerts, shows, or festivals. At the beginning of the year she stated that if she never was required to take another science course then she definitely would not.

The first premise of the model states, "The universe is open to human description, classification, and understanding through scientific exploration." Like all participants in this study, Dorothy believed that the universe was indeed open to human description and classification through scientific investigation. Her understandings of this aspect of the premise remained unchanged over the course of the year. She believed that humans had the capacity to uncover information about the universe through science, but that "we'd find little things bit by bit, but not everything at once." She also believed that we could not come to know everything there is to know about the universe, and that there would always be more to learn.

Dorothy never discussed other ways besides science in which humans might

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come to understand about the universe, such as through spiritual inquiry. When I asked her during the second interview as to why certain knowledge might be considered scientific, she responded "because it doesn't fit anywhere else!" Her understandings of this aspect of the premise were incomplete and unchanging, leading to only a partially formed conception regarding this overall tenet of the model.

Like many students, Dorothy believed that "everything is science," or if not science itself, was certainly related in some way. Examination of the second premise of the model, "This scientific exploration attempts to explain and predict phenomena, compare theories, check on previous results, and generate new questions" helps highlight this point. During the first interview when I asked her to define science, she replied, "Define science? Science is the study of everything really. You can find the science in everything. A book, a chair, a person." Later during that first interview, when describing what she had done thus far for the watershed project, she noted that the class had "made comparisons" and was "evaluating things" which was characteristic of science. During the third interview, I asked Dorothy to define science again:

To me science is, um, the study of, um, nature [pause] what makes up nature and the world, like as far as chemistry and the human body. It has to do with chemistry, what makes up something.

During the fifth interview, she defined science as "involving facts, scientific proof, a theory about some scientific meaning." When I asked her if there was a general goal to all of science, she responded with a now familiar phrase, "I think it's trying to figure out how it works, how something works." Although Dorothy's definition of
science changed somewhat over the course of the year, becoming seemingly more narrow and focused in the middle of the year, at no point would I consider her conception of this premise fully formed. She seemed to make use of vocabulary which is descriptive of science, such as "theory," but was not able to explain what she meant by her statements. She seemed to have a general view of science which centered around the notion of "explaining," but never mentioned prediction, checking on results, or generating questions as characteristic of science.

The next premise of the model states, "Logic, imagination, curiosity, and serendipity contribute to scientific exploration." Although Dorothy believed that a scientist must be "inquisitive with everything," she never discussed imagination or serendipity. Logic was not discussed either. Therefore, her conception of this premise, which remained consistent, cannot be considered fully formed. However, it is important to note that she did stress the importance of curiosity, or inquisitiveness, throughout the entire year.

"Scientific activity is a social activity conducted by individuals who are influenced by both cultural and personal factors" is the next premise. Dorothy's understandings of science as an enterprise which is partially shaped by the needs of society were fixed and only partially conceived. During the first interview when I asked where scientists come up with their ideas for study, she responded quite vaguely, "I guess they just come up with them." During the third interview she also stated that scientists themselves are responsible for deciding what to research. During the fifth interview, when discussing where scientists get their topics for research she
similarly stated, "Um, I just think (scientists) themselves really...they've always had an interest in science...because they want to find out why something happens, I think." In addition, during the same interview she said, "Oh scientists it's an easy job because they just sit around researching the same thing for 20 years, get nowhere, get paid millions of dollars because they have a degree..." She viewed scientists as being very focused and working only on what they desired, perhaps even for as long as an entire career. She never mentioned their research being guided by societal pressures and needs.

The second part of the premise relates to science as an activity which is conducted by individuals who are influenced by personal factors. Although her understandings were once again unchanging, for this portion of the premise they were fully formed. From the very first interview Dorothy commented that scientists may be biased. She also stated several times over the course of the year that scientists have opinions. She concisely summed up her beliefs regarding this area in the fourth interview when she stated, "Scientists are humans too. They're not just computers that spit out facts without any opinions themselves." She also commented that if two scientists conducted the same research that they would not necessarily come up with the same results. Most students cited external factors for this reason, such as technological limitations. However Dorothy noted that the way in which a particular scientist designs a study may have an impact on the outcome. That is, she believed that scientists and how they go about conducting science will have an influence on the process of science itself. She viewed scientists as humans, closely tied to the scientific
endeavor, not detached from it.

"Questioning, data collection and analysis, drawing of conclusions, and communication are the major phases which characterize the scientific endeavor" is the final premise which describes the nature of the scientific enterprise. Although Dorothy was able to list various steps of the scientific method throughout the year, her unchanging understandings were never fully formed. During the first interview, after she commented that she wasn't sure of the steps, I asked her to list them the best she could, "Hypothesis [pause] procedure [pause] hypothesis, procedure, um, results and conclusion." During the second interview, although she had extreme difficulty recounting the actual steps again, Dorothy did comment about the purpose of the steps by saying, "It's an ordered process in order to find something like for a project. An ordered process to keep you on-task..." Once again in the third interview, she attempted to list the steps as best as she could remember, "First you have your hypothesis, your procedure, and then your results, I'm sure there are more things in between..." Her comments were similar for the fifth interview.

At several points throughout the year Dorothy mentioned that she wasn't surprised that she couldn't remember the actual steps because she hadn't gone over them in science class since her freshman or sophomore year. However, she did note "I think we've been following them" in the Conservation Biology class even though she wasn't sure what they were. Although she did know that the steps were an ordered process, and even commented that a hypothesis might be "what you think might happen," she was unable to describe the rationale for most of the individual steps.
Perhaps she confused them with the set up of a lab report which is why she mentioned "procedure" when describing the scientific method. At no point in the year did she mention problems or questions as setting the stage for conducting scientific research, and in addition she did not ever discuss the communication of results as being part of this process. Her overall conception of this premise was therefore incomplete.

Although Dorothy did not explicitly discuss questions and questioning with regard to the scientific method, I did inquire about questions in science throughout the year. She defined her science foundations courses as question oriented. When describing these classes she stated:

Dorothy: Well, last year anyway [pause] all three years actually was questions. Asking a lot of questions. Asking questions like what makes something do something. Why is that like that? What, why, when, how kind of questions, and then answering them.

D: Can you give me an example of something that you did last year that started with a question? Do you remember?

Dorothy: We did a lot of like projects, which is what foundations really is. We did one on making a clock. You had to come up with your own way of how to measure time.

Dorothy stated that there were essential questions in her Conservation Biology class, but at the beginning of the year when I inquired what they might be she second guessed herself, "I think we do anyway. Um...", not being sure what they were. Like Heather, she noted several times throughout the year that there were indeed questions guiding each class project, but answered "I know we've had some..." and "I don't remember what it is" when asked what they were. Also like Heather, she was at least aware of the various themes which guided each project, such as forest health, even if she said referring to the Forest Watch project essential question, "I couldn't even begin
to tell you the exact words." Dorothy noted that the questions for each class project were provided for her except for the salmon project in which she was able to develop her own question for study. Although she answered, "I wrote my own," when I inquired about this question she once again replied, "I don't know, I forgot," not remembering what it was.

Dorothy's explanations of the remaining steps of the scientific method were generally poor. She liked the idea of doing what she described as "hands-on" work for the watershed project, which was the data collection. She stated accuracy was important in data collection even if she could not think of ways in which the class tried to be accurate during the projects. When I asked her what data analysis involved, she replied, "I have no clue," which was not entirely true. She demonstrated having a general idea of what this phase of the scientific enterprise involved. For example, she noted data analysis might involve "comparing information" among students in the class, although she was unable to elaborate further. Dorothy had very rudimentary ideas about all of these areas.

The first premise of the model which relates to the nature of scientific knowledge states, "Scientific knowledge demands evidence, and is testable through the scientific enterprise." At the beginning of the year when I inquired about what makes certain knowledge scientific, Dorothy eluded to the notion of empirical observation when she stated, "when you can actually see it." She said that a dragonfly is green, you can see it, and that makes it a scientific fact. During the third interview our conversation unfolded as follows:
D: Let's say, I just state that I think that this note pad can provide limitless energy for New Hampshire. Just this pad. Is that science? Is that claim science...?
Dorothy: I don't think so.
D: Why?
Dorothy: Because you need to see how you think that, how that is true.

She also stated that scientific facts need to be proven. During the fifth interview she also repeated this belief, and stated that one may have to keep studying something a long time in order to achieve the necessary proof. Therefore, although she was unsure of the exact means by which scientific data is generated, as seen by her poor understandings of the previous premise, she did hold partial conception of this premise which underscored the importance of "proof" in determining if knowledge is scientific. Her understandings remained consistent over the course of the year.

The next premise states, "Scientific knowledge cannot provide complete answers to all questions," and Dorothy's conception was fully formed and unchanged over the course of the year. She described science as "a never ending process" early on in the year, and noted during the third interview that "things always change" which is why questions could not be fully answered. As mentioned earlier, she commented that scientists work on the same topic for years and years and cited that reason as additional evidence that questions could not be fully answered.

The final premise of the model states, "Scientific knowledge is tentative, developmental, and subject to revision." Dorothy's conception of this final premise was fully formed and consistent over the course of the study. During the second interview she commented that scientific knowledge is always "changing." During the third interview she also noted that "results can always change" and that nothing is fixed.
During the fifth interview she addressed the developmental nature of scientific knowledge when she discussed the value of "older knowledge":

Well you could see that maybe in another ten years it might change back to what it originally was or you know just keep on comparing everything to see the direction that it is changing.

She believed that scientific knowledge does not go out of date.

The next sub-section will briefly discuss Dorothy's opinions of the project-based Conservation Biology class, and the following sub-section will summarize her conceptions of the nature of science.

Conceptions of the Project-based Class - Reflecting on the class at the end of the year Dorothy said that she liked the class a lot, and that it was "challenging," even though she does not consider herself a science person. She had praise for the teacher, Daria, whom she thought of very highly. Like many students she preferred the active nature of the class, stating about midway through the year, "I liked going outside and just being involved in a hands-on project" referring to both the watershed project and Forest Watch projects.

This project-based science class, unlike others such as the foundations classes, seemed to foster a change in the relevancy of science to her everyday life:

Dorothy: I just didn't think (science) related to life. I was like, how does the solar system relate to me, and how does, you know, learning the planets and how many moons it has, and I always thought that was kind of stupid.

D: But now?

Dorothy: But now I see, now that we're doing things that are actually in my backyard and actually that relate to human beings, about how we progress on as society, how then that relates to us and what we're doing. And that I think that made me more interested.
She also felt that science was now "more realistic" for her than it was before, because she thought she experienced in class what actual environmental scientists might experience. She particularly liked the salmon project in which she was able to explore the "human" aspects of science. That project dealt with the political and historical aspects, in addition to the scientific aspects, of restoring salmon to New England waterways.

The student scientist partnership (SSP) aspect of the class also seemed to help make the class projects more relevant to her. She commented that being in partnership helped make the Forest Watch project more "real." However, although she viewed the Conservation Biology class and the scientists at UNH as working together, she commented that we "just send the information in" when describing the nature of that partnership. She noted "We're not the ones who are going to analyze it, they are." At the very end of the year, I asked if the class was going to participate in any data analysis, and she said the class had done some "group analysis," but she expected UNH to handle the analysis of the project. This lack of conclusion did not seem to lessen the enjoyment of the project for her, however. Perhaps for her it even helped define a clear role for the Conservation Biology class in the partnership. Valley handled the data collection and UNH handled the analysis.

Even though Dorothy enjoyed this class, she reiterated her view at the end of the year that she would not take another science class unless she absolutely had to in college. She was accepted to a small liberal arts college in New England, and was looking forward to someday working as an event planner.
Summary - Like all participants in this study, Dorothy believed that the universe was open to human description and classification through scientific investigation. This belief remained unchanged over the course of the year. She did not discuss other ways of inquiring about the universe besides science. She believed that "everything was science" or that science was somehow related to almost everything, reiterating that point throughout the year.

Dorothy's definitions of science changed somewhat over the year, however at no point would I consider her understandings of the second premise to be fully formed. She seemed to make use of vocabulary which is descriptive of science, but rarely was able to explain what she meant by her statements. She seemed to have a general notion of science, but never mentioned prediction, checking on results, or generating questions as, in part, defining science.

Although Dorothy believed that a scientist must be "inquisitive with everything," she never discussed imagination or serendipity as contributing to the scientific enterprise. Therefore, her unchanging beliefs regarding this premise were incomplete. Dorothy's understandings of the next premise were mixed. They were partially conceived concerning science as an enterprise which is somewhat shaped by the needs of a society. However, they were fully formed in relation to the second part of the premise, that science is an activity conducted by individuals who are influenced by personal factors. She believed that scientists and how they went about conducting science were not detached from that process, but human and influenced by personal factors and experiences. Her beliefs regarding this premise remained fixed.
Although Dorothy was able to list various steps of the scientific method throughout the year, her unchanging understandings were not fully formed. She wasn't surprised that she couldn't remember the actual steps because she stated that she hadn't gone over them in science class since her freshman or sophomore year. However, she did note "I think we've been following them" in Conservation Biology class even though she wasn't sure what they were. At no point in the year did she mention problems or questions as setting the stage for conducting scientific research, nor did she ever discuss the communication of results as being part of this process. Dorothy's explanations of the rest of the steps of the scientific method were generally poorly conceived.

Although she was unsure of the precise means by which scientific data is generated, as seen in her understandings of the previous premise, she did hold a fully formed understanding regarding scientific knowledge demanding evidence. Her beliefs which underscored the importance of the notion of "proof" remained consistent over the course of the year. Dorothy's conception was also fully formed and unchanged regarding the next premise. She described science as "a never ending process," believing that scientific questions could not be fully answered. Finally, Dorothy addressed the developmental and tentative nature of scientific knowledge when she discussed the value of "older knowledge," and how knowledge is always "changing." Her fully formed conception of this final premise remained unchanged over the course of the year.
Lisa

Being a senior and short on science credits, Lisa needed the Conservation Biology class in order to graduate from Valley. Like Dorothy, she did not describe herself as a science person, stating "Science is not my thing," and as far as she was concerned would never take another science class again if it wasn't required. Although she was typically a poor student, she was hoping to gain acceptance to college immediately after high school to study photography. Her senior project was related to photography and images in advertising, and she spent a great deal of time working on this project during her senior year. The final project did not come easily for Lisa, but she was determined to do well and graduate on time. Between her normal course load, the senior project, and part-time work after school, it was a challenge for Lisa to keep up with all of her responsibilities.

During her ninth grade year Lisa had enrolled in the Foundations I science class, and took Foundations II during her sophomore year. She elected not to take a science course her junior year. Her most positive experience in science class happened during her seventh grade year, when she was attending school in another district. She described this class as follows during our first interview:

In seventh grade I was in a different school and (the teacher) taught us how to do experiments, like he'd just say 'What happens when...?" yeah, it was hard, but it was fun. It was all individual, we didn't work together, we all had packets and we worked by ourselves. He just gave us like, we just wrote up lab reports and then he would quiz us on what we knew. He'd take our lab report and ask us questions from what we learned. That's how he graded us.

She made mention of this class numerous times during the year, often commenting that she liked the independent nature of exploring topics on her own. She described
the balance of her secondary school science classes as too structured, and usually boring.

The first premise of the model of the nature of science states, "The universe is open to human description, classification, and understanding through scientific exploration." Lisa only held a partially formed conception of this premise, because at no point throughout the year did she address other ways of knowing than those which would be considered to be scientific. However, she believed that science allowed humans to describe "things" about the universe. She stated that we could never know all there is to know, and summed up her beliefs toward the end of the year:

I think there are limits. You know, there are some things that are just known as facts and that's the way that they are and then there are some things that you just can't figure out. I mean it depends on the technology, you know, that comes out next. I think that like as the technology advances, science advances.

Lisa's understandings did not evolve over the course of this study.

Like other students, Lisa believed that "everything is science." She stated during the first interview that people think about science "whether we know it or not." During the third interview she stated that people think of science all of the time, "whether we are conscious of it or not, just wondering why things are, how things are..." Later in the year she commented that science is done "everywhere, whether you notice it or not." During the final interview she reiterated her beliefs when she stated, "I think we use (science) without even knowing it a lot of the time." Throughout the course of the year she consistently held this notion that individuals "unconsciously" think about or participate in science in their everyday lives.

However, at no point did she fully explain her beliefs, other then remarking
several times that during her seventh grade class she came to understand how science is prevalent in our everyday lives. As stated earlier, this class had a tremendous impact on her notions of science class, and science in general. Lisa's belief that everything is science may be similar to the one described in the description of Ben's beliefs from Woodland. I believe her conceptions may have come about through science instruction in which her science teacher attempted to explain the relevancy of science when perhaps answering a question such as "Why do we have to learn this?" Lisa has taken the notion that science can be seen in much of our daily lives and extended it to believe that whether we know it or not, everything is science. This "everything is unconsciously science" belief was confirmed through informal interviews during participation observation as well.

The next premise which served as a definition for science states "This scientific exploration attempts to explain and predict phenomena, compare theories, check on previous results, and generate new questions." During the first interview, Lisa defined science as follows:

Lisa: Um [pause] I don't know. I guess it would be gaining knowledge about our surroundings and also trying to figure out ways to better our surroundings. I think it's in a lot of different things that we do...I think it [pause] we can use science by the environment and by products that we make, and in research for medicines. A lot of different uses.

D: What do you mean by research?
Lisa: Just trying to find new things and to experiment. To gain more knowledge of things that we don't know...you know like trying to find the unknown.

During the second interview she described science using the familiar phrase of determining "how things work." She also noted that it is characterized by "exploring"
the unknown. During the third interview she stated science is:

Um [pause] new knowledge about your surroundings and learning new things. I think it can cover a lot of fields. Nature and chemistry, like chemicals, I think it has to do with a lot of different things. I think its just the study of how things work and why things happen.

During the fourth interview she defined science as, "Learning about the environment and how things work and just answering the question of like why and how and stuff like that." Additionally, she explained that there were both physical science as well as life science, and that they are characterized by "trying to come up with a conclusion."

During the fifth interview she stated that science is "discovery" and "learning about your surroundings." She also added that a goal of science was "to learn new things and to be familiar with the way things work." Finally, during the last interview of the year, regarding science she stated:

It would definitely have to do with like discovery. Just of like...already known knowledge and discovery of new knowledge. I think it has a lot to do with discovery...I think that in science you need to be able to be adaptable in your thinking ways. I don't think that you can do experiments saying like this has to be the conclusion. I think you have to be very adaptable to like different things that change and stuff like that.

Although her understandings about science changed somewhat over the course of the year, focusing on more applied science at the beginning of the year, there were some common elements to her descriptions, such as discovering "new knowledge." She mentioned questioning approximately midway throughout the year along with focusing her explanations toward specific content areas. Perhaps like Heather, following the salmon restoration project in which she had the opportunity to choose her own question for investigation, at the conclusion of the project she began to consider
questions as, in part, defining science. Her question was, "What is the difference between landlocked and atlantic salmon?"

Lisa certainly believed that science can explain phenomena, and her understandings of this evolved somewhat over the course of the year. At the end of the year she also mentioned that one aspect of science is checking on previous results. She never specifically discussed the notion of prediction, theories, or generating new questions, therefore her overall conception of this premise was not fully formed.

The next premise states, "Logic, imagination, curiosity, and serendipity contribute to scientific exploration." Regarding this premise, Lisa's unchanging conception was partially conceived throughout the year because she never discussed serendipity as contributing to the scientific enterprise. During the early part of the year, Lisa stated that scientists need to have an "inquiring mind," but perhaps just as important, they need to "want to be finding something new in order to do what they're doing." Referring to the balance between logic and creativity in science, our conversation went as follows during the third interview:

Lisa: I think (science) definitely has creativeness in it, but I think it needs to be more analytical and more straight and narrow and follow some rules. Not all rules because then you would not find anything new.

D: How does creativity come into it?

Lisa: Just thinking of something completely different. I don't know, I think you have to have a little creativity to think of an idea. Like, if you are inventing something it takes creativity in science. It depends on what you are doing.

Toward the end of the year Lisa also noted that scientists needed to be intelligent and creative if they are going to try to figure out how to solve problems. She said "being curious" was also an important characteristic of individuals working in science,
reiterating her belief from the beginning of the year. She held full understandings of the roles logic, imagination (creativity), and curiosity play in science.

Lisa held similar conceptions as Larry from Woodland when discussing the role of men and women in science. Like Larry, she believed men are more logical and perhaps better suited for scientific work. At several points in the year she discussed the notions of "left and right brained people," and stated that there are probably more men than women in science because, "I think that more men like are more brainy I guess. You know? I think more women are more creative." Although she stated that creativity was important to science, being "brainy" was even more so. When I inquired about her idea of a typical scientist, like most participants in this study she described an "Einstein like" individual with a lab coat, thick glasses, crazy hair, and a propensity to blow things up. Like Lisa, most participants described men when outlining their image.

"Scientific activity is a social activity conducted by individuals who are influenced by both cultural and personal factors" is the next premise of the model. Lisa's understandings of science as an activity influenced by society/culture were partially formed and did not evolve over the course of the year. At both the beginning and end of the year, she stated that scientists themselves are responsible for deciding what to research, without ever discussing the notion of problems or societal needs as, in part, setting the scientific agenda for modern science. During the fifth interview I asked where ideas or topics for scientific investigations come from, and she responded:

I don't know. They come from like multiple places like their heads and like just other people asking questions or just saying, 'Wow I've never seen that before!' - actually being curious and like trying to figure it out.
She had no idea where funding for scientific research came from, nor did she know where professional scientists might be employed.

Her understandings of science as an activity conducted by individuals influenced by personal factors were also unchanging and partially conceived. For example, she believed that if two scientists conducted the same type of research, they would make the same conclusions unless there was a difference in the technology they used. For Lisa, external factors such as available technologies were the primary means by which science may be influenced. At no point did she discuss science as a human endeavor in which human factors, such as prior experiences or personal preferences, may affect the process of science itself. Her conception of this overall premise was incomplete.

"Questioning, data collection and analysis, drawing of conclusions, and communication are the major phases which characterize the scientific endeavor" is the final premise of the model which deals with the nature of the scientific enterprise. Lisa's conception of the overall scientific method was fully formed and consistent over the course of the year. Throughout the year, as mentioned earlier, she stressed the importance of science gaining "new knowledge." She discussed that the "steps" which characterize the scientific endeavor, or "experiments" as she referred to them, were the process by which developed new knowledge. Toward the end of the year I inquired if she had gone over these steps during Conservation Biology, and she replied:

Lisa: No. I did that in the seventh grade. Yeah. I had like an awesome science teacher and we did our own experiments. He'd say his problem and we'd have to write down like title, objective, procedure, materials. Like we'd have to figure out everything. Like he'd be like, ok how do
you figure out why metal goes to a magnet. We'd be like all right...I mean, he really made us think. Like we had to figure out everything for ourselves.

D: So have you used those this year at all?
Lisa: Not like in a formal way. Probably in some way.

Like Heather who stated that the class "seemed to make use of the steps," Lisa believed that the Conservation Biology class made use of these steps "in some way," but there was no formal treatment of them. Like Dorothy and other students, Lisa commented that she had only learned the steps in previous years, which is why she had difficulty listing them "exactly."

Lisa discussed several times during the year that questions are important to science. Like both Heather and Dorothy, she noted that in the Conservation Biology class the questions were generally provided except for the salmon project in which she had the opportunity to choose her own question. At the end of the year, we discussed essential questions and their role in this project-based class:

D: What about essential questions this year? Did you use those a lot in Daria's class?
Lisa: Essential questions? Yeah, for like every main part, like every main subject like we had an essential question. That's the case in all the classes in this school. You always have essential questions.

D: Are they good? I mean do they help with the classes...?
Lisa: I think they work at the end of the project. You tie everything together to answer that essential question...just so that you can do research...and so I guess it gives you more of a direction, you know... it kind of keeps you in line, in the right direction because you know the main thing that you're looking for.

D: So what are some of the essential questions for Daria's class?
Lisa: I don't remember exact essential questions.

D: So they're not the kind of thing that you use every day then? Do you think every day, what's my essential question...?
Lisa: No. No. The only like project I ever thought that is senior project essential question.

D: Ok. So do you feel like if there were no questions at all, you could've
done Daria's class? I mean could you have done it without the essential question and it would've worked just as well do you think?

Lisa: I don't know...it depends on like what (project), like I think for the water quality it was good to have an essential question because it was you know something about like water quality...so I think it depends.

There are several important points to note from this dialogue. Although essential questions were widely utilized in all classes throughout Valley, including Conservation Biology, the most important essential question for Lisa was the one she developed for her senior project. While working on her senior project she came back to the essential question again and again to guide her work throughout the year. This was not so for her project-based work in Conservation Biology. She commented that although essential questions helped to keep the class focused on the topic at hand, she didn't know the essential questions for the class projects and may have been able to have gone through the class without them. However, like other students, she did know the themes of each project which were representative of each essential question.

As did other participants in this study, Lisa viewed data collection, data analysis, and drawing of conclusions as being very closely related. She defined data collection as "testing" and provided an example of data collection by citing the pH tests at the river. She considered data analysis and drawing of conclusions as "looking at our information" and "the comparison" of information acquired through data collection. She viewed the analysis as "the reason for what you did." Referring to making all of the extensive data collections for the river project, she noted it was where the class concluded that "the river was pretty clean."

Lisa expressed her beliefs about the importance of presenting results when we
discussed this topic during the first interview:

D: Is presenting part of science?
Lisa: I think so. It shows that you learned something. If you can present something then I think that you learned it. If you can present it and make it understandable.

Since much of the formal assessment at Valley is based on presentations, perhaps it is not surprising that she thought of presenting in this way. She associated conclusions with presenting, stating about midway through the year that at the end of a study one arrives at conclusions and then shares that information. She also noted that she enjoyed and valued informal communication with her peers in class.

The first premise of the model that deals with the nature of scientific knowledge states, "Scientific knowledge demands evidence, and is testable through the scientific enterprise." Lisa's conception of this premise was fully developed and unchanged over the course of the year. During the second interview she noted that somebody had to research scientific facts in order to determine if they were true. She stated that "you should be able to back up what you found," and that constitutes "proof." When I inquired how one might go about proving something in science, she replied, "By doing an experiment and coming up with a result." Similarly, during the fifth interview when I asked if there was a special way to prove scientific knowledge, after she said it had to be proven, she again commented that "experimenting" was the only way to prove if something was indeed fact.

The next premise states, "Scientific knowledge cannot provide complete answers to all questions." Lisa held a fully formed conception of this premise based on the model, but altered her beliefs toward the end of the year.
she stated, "I don't think anything can be completely done. There is always another aspect to everything..." During the third interview she stated explicitly that scientific questions could not be fully answered. However, during the fifth interview she added that sometimes questions could be fully answered, noting that "the Earth was round." Although she felt most of the time they could not, depending on the question perhaps they might. This shift represents a change in her conception. There is no data to suggest why at the end of the year she thought that sometimes scientific questions could be fully answered in addition to her belief that most of the time they could not.

The final premise of the model states, "Scientific knowledge is tentative, developmental, and subject to revision." At the end of the year Lisa described the developmental and tentative nature of knowledge when she said she viewed older scientific knowledge as "a step to finding the knowledge." She viewed knowledge as existing on a continuum, stating that what new knowledge we find is "part of the (old knowledge), it's just that there is more added on." This represents a change in her conception of this premise from the beginning of the year. She stated several times at the beginning of the year that "something drastic" would have to happen for knowledge to change. She could not cite factors which might contribute to a drastic change, and therefore did not believe knowledge could change.

Toward the end of the year she incorporated her notion of technology as contributing to the evolution of knowledge. She stated, "I think that it can change with technology. You know maybe find something out that you never could've found without the new microscope or something." Perhaps her work with computers to view
satellite data and microscopes to analyze white pine needles for cellular damage in the Forest Watch project contributed to her belief that technology can contribute to new knowledge. This might, in part, account for her belief that knowledge could evolve because she now understood a means by which it could do so. Ultimately, she had a full conception of knowledge as tentative, developmental, and subject to revision as described in this premise.

The next sub-section will briefly discuss Lisa's views of the project-based Conservation Biology class, and the following sub-section will summarize her understandings of the nature of science.

Conceptions of the Project-based Class - Although it was clear that the most positive science experience Lisa had was in her seventh grade class, she did enjoy this class much more than the foundations classes which she described as "boring." She had tremendous respect for Daria, and numerous times over the year commented that Daria was an excellent teacher. Lisa believed that Daria really cared about the environment, and at the end of the watershed project Lisa said that the Conservation Biology class made her appreciate nature a little bit more:

Well, in my past classes we have never really done anything with water, we did the oceans, but we didn't [pause] It made me think about the water around us and the quality of it and how many things go on. I never [pause] I just looked at the water and that's pretty. Now I realize how many little things live in it and what happens to it and how things effect it.

Later in the year, reflecting on the watershed project she noted that "It affected me, I found it interesting...I just felt it to be closer to me," referring to that fact that the class worked in a local river as opposed to just studying science in general. She felt
like that project was "real science." During the fifth interview I asked her if there was a difference between real science and school science:

Lisa: Yes, I think so because, well [pause] it depends what school you're in. Because some schools I think basically all they're trying to do is just give kids the basic knowledge that they need in order to move on into other science fields. I think (school science) is more learning not discovering. But I think sometimes in the process of learning, you do discover.

D: Do you like that part better? The discovering...
Lisa: I don't know. I mean like I think the whole entire river thing, I think that was more of like discovering and learning because we were learning how to do something but also at the same point we were discovering whether or not it was really dirty or not and you couldn't look that up in a book. You know?

She thought her experience with the river project might be similar to her experience in her seventh grade class. Referring to her seventh grade experiences, she said, "I mean you remembered the stuff because you were the one who really found it out..." She thought she would remember what she learned in this class as well. Perhaps, the final evaluation of the effectiveness of the project-based format of Conservation Biology can only be made several years down the line when we may have the opportunity determine what Lisa actually learned from this class experience. Considering that during the final interview she stated, "If I have my choice, I would never take science again," this class experience becomes even more important.

The experiences that Lisa received in the rest of the projects were not as positive as the watershed project. I believe that this negativity was due to the fact that she became extremely busy with her senior project as the year progressed, and seemed to focus on that effort more than anything. She viewed that project as a "do or die" hurdle, because she knew that she must pass that project in order to graduate from
Valley. Lisa did pass her senior project and graduated from Valley with her class. She is currently attending a college in the midwest and studying photography.

**Summary** - Lisa believed that science allowed humans to describe and classify our universe, but that we could never know all there is to know. She believed that "everything is science," consistently holding the belief that individuals unconsciously think about or participate in science in their everyday lives. She did not address science as merely one way of knowing, therefore her conception of the first premise was incomplete.

Lisa's definition of science changed somewhat over the course of the year, however there were some common elements throughout the year to her descriptions, such as discovering "new knowledge." She never specifically discussed the notions of prediction as in part defining science, and her overall conception of this premise was incomplete.

Regarding the aspects of logic, imagination, and curiosity contributing to scientific exploration, her understandings were unchanging and fully formed throughout the course of the study. Although she stated that creativity was important to science, being "brainy" was even more so. She believed that men were more logical than women and that they would often make better scientists. When I inquired about her idea of a typical scientist, like most participants in this study she described a male with a lab coat, thick glasses, and crazy hair. She never discussed serendipity and therefore her overall conception of this premise was also incomplete.

At both the beginning and end of the year, Lisa never discussed the notion of
problems or societal needs as, in part, setting the scientific agenda for modern science. She also had no idea where funding for scientific research came from, nor did she know where professional scientists might be employed. Regarding science as an activity conducted by individuals influenced by personal factors, her understandings were also unchanging and not fully formed. At no point did she discuss science as a human endeavor in which human factors such as prior experiences may affect the process of science.

Lisa's conception of the scientific method was fully formed and consistent over the course of the year. She had a good understanding of the importance of questions and their role in science, however she also stated that she didn't know the essential questions for the class projects and may have been able to have gone through the class without them. Like several participants in this study, Lisa viewed data collection, data analysis, and drawing of conclusions as being very closely related. In addition, she thought communicating results in science was important.

Regarding the first premise of the model that deals with the nature of the scientific knowledge, Lisa's conception was fully formed and unchanged over the course of the year. She stated that "you should be able to back up what you found," and only that constitutes as "proof." Her conception of the next premise which refers to questions and questioning was also fully formed. During the fifth interview she added that sometimes questions could be fully answered however she felt that most of the time they could not. There is no data to suggest why her beliefs changed.

In relation to the final premise, Lisa viewed knowledge as existing on a
continuum, stating that what new knowledge we find is "part of the (old knowledge), it's just that there is more added on." This represents a change in her conception from the beginning of the year. Ultimately, however, she fully understood knowledge as tentative, developmental, and subject to revision as described in this premise. Her experiences with technology may have contributed to this shift.

Roy

Based on academic achievement, Roy had been an excellent student for most of his school career. He was a junior during this study, and was a popular and outspoken individual in class. He described himself as an "outdoors person" who enjoyed mountain biking and hiking, and enrolled in Conservation Biology due to what he perceived as the hands-on, outdoor nature of the class. Although he described himself as a science person, he stated in the first interview that he was "no Einstein." He said that he didn't think of himself as what he described as a typical scientist working in a laboratory, but a "flannel shirt kind of guy" who saw himself someday working as an environmental scientist "up in Alaska checking out bears and stuff."

Like many students, he enrolled in Foundations I in ninth grade and Foundations II during his sophomore year. He described Foundations I as encompassing the physical sciences and Foundations II focusing on the life sciences. He was quite critical of those classes, stating that they weren't challenging and often quite boring. Although he was also somewhat critical of the Conservation Biology class, he had different criticisms. Even though he generally enjoyed this class, and had
great respect for Daria, he stated that at times he was unclear about exactly what the expectations were pertaining to some of the project-based work. He felt more comfortable with the aspects of the projects in which Daria told the class exactly what to do. When he experienced what may be described as "real science," in which no "canned" or predetermined answers existed, he felt the class lacked focus and he was frustrated.

The first premise states, "The universe is open to human description, classification, and understanding through scientific exploration." Roy held a partially formed conception of this premise which remained unchanged over the course of the year. He stated that in many cases scientific questions were difficult to answer, and that "it might take a lot of work" to uncover them, but felt that science could definitely serve as a means by which humans could describe and classify the universe. However, similar to several participants, he believed that "everything is science," and never discussed other ways of knowing which might differ from a scientific one.

Roy's understandings of the second premise, "This scientific exploration attempts to explain and predict phenomena, compare theories, check on previous results, and generate new questions" can help clarify his beliefs regarding the "everything is science" phenomena. During the first interview he defined science as being method driven:

D: So, what is science?
Roy: Science is like everything I guess. Studying stuff that is around. That isn't around, but might be around earlier or in years to come.
D: Is there something that is not science?
Roy: No, I think everything has a science to it. Baking cookies you have to add the right amount of eggs and milk and stuff like that.
D: Why is that science?
Roy: Because, there is a way to do it and if it doesn't work [pause] if you don't do it the right way [pause] there is a method to it and an outcome...there has to be a method to the madness.
D: Why?
Roy: Because if you don't follow a method you won't get anywhere...

Not only did he state that "everything has a science to it," but supported his answer with an explanation which indicates that he believes that an organized method of doing something or a prescribed set of procedures is what is characteristic of science. In addition to stating that there is a science to baking cookies, he also described the "science" in building a house:

Say I wanted to build a house, there is a science to that. First I need to say I want to build a house and how I am going to do it. I need to figure out what I need for materials, then I get the materials. Then I figure out how to do it, hire people, get the tools that I need. After I have the materials and the know how then I actually have to start doing it...

Roy said there was a "science" to fixing his car as well. He believed by using what he described as the "steps" of science and "problem solving skills" in general, he was in fact doing science. His beliefs were similar to Ben, from Woodland, who also considered an activity to be scientific if there was structure, organization, or a "certain way" of doing it. Both participants confused the organized, systematic nature of science with science itself.

During the third interview, Roy's definition of science was quite succinct. He explained science as, "Doing stuff like finding out things, using like steps and methods..." During the fourth interview Roy discussed theories. He defined a theory as something "a scientist hasn't proven," and noted that it is the job of a scientist to test, or try to disprove or prove theories. He provided an example of this idea by discussing
work from a science class from a previous year in which the teacher brought in photographs of the same landscape area taken on two different dates. He explained that in the earlier picture there were many trees and in the later one there were only a few. He said that the teacher described this area as being down wind from a paper mill plant and noted that the theory was that acid rain was killing the trees. He thought it would be a scientist's job to test that theory, because until someone does there is no real way to know what killed the trees. During the fourth interview, as well as during the second interview, Roy described science as work that dealt with mathematics and the use of equations or numbers during data collection and analysis. He thought counting and averaging numbers were characteristics of science.

During the fifth interview, Roy also provided a concise definition of science which was similar to an earlier definition he gave, stating, "Science is...a certain series of steps that you take to derive the answer, I guess." He never discussed prediction, checking on previous results, or generating new questions as defining science, so his unchanging conception about this premise was incomplete. He held a full understanding of science explaining phenomena and comparing theories, believing that science was method driven.

The next premise states, "Logic, imagination, curiosity, and serendipity contribute to scientific exploration." Roy's conception of this premise was incomplete and unchanging over the course of the year. He did not discuss serendipity as contributing to the scientific enterprise. Like many students Roy believed that scientists should be imaginative and creative "in order to figure things out," but stated
that logic and perhaps even inquisitiveness, or the desire to know things, are even
more important to science. He had a full understanding of these aspects of this
premise.

The next premise of the model states, "Scientific activity is a social activity
conducted by individuals who are influenced by both cultural and personal factors."
Roy's understanding of science being influenced by cultural/societal factors was fully
formed and consistent throughout this study. During the year he often discussed the
societal influence over science. During the second interview he stated science was, in
part, driven by the need "to get cures for diseases." During the third interview he
noted that "private corporations, grants, the government, and hospitals" paid scientists
for their work. Later in the year he stated:

I think hospitals and like medicine companies fund science because you know
they're in the business of health and science...and big companies might fund
science if it's beneficial to their company...I just think that most grants that are
funded (are) for the purpose of helping the company or organizations giving
money...

In the fifth interview he summed up his beliefs by stating that it was mostly "a
problem that (scientists) have or that somebody has presented to them" which actually
guides science.

In reference to science as an activity which may be affected by personal
factors, Roy's understandings were consistent, yet only partially formed based on this
premise of the model. He only referenced "external factors" contributing to scientists
reaching differing conclusions when conducting the same research. During the third
interview he stated:
There are variables. It depends what the study is. If (scientists) are studying mating habits of chimpanzees then different chimpanzees are going to act different. But if they are studying what will happen when you drop a two pound marble off a two foot cliff then it will probably do the same thing every time. It depends on what they study.

During the fifth interview his comments were quite similar:

It depends. There's a lot of variables...if you're dealing with an animate situation where it's studying bears or whatever, the bears aren't going to always act the exact same way, so they'll probably get something within the same parameters but not exactly the same.

His understandings of the variability in making naturalistic observations are accurate. That is, chimpanzees and bears will exhibit a variety of behaviors which may lead scientists to make conclusions that may not be exactly the same, only within "the same parameters," however he never discussed the scientists themselves as being susceptible to the same "natural variability" as animals. He did not discuss science as a human endeavor in which personal factors may affect how the scientist behaves within his or her own environment when designing the research, collecting the data, or analyzing and reporting the results.

The final premise of the model which deals with the nature of the scientific enterprise states, "Questioning, data collection and analysis, drawing of conclusions, and communication are the major phases which characterize the scientific endeavor."

Roy addressed questions, hypotheses, getting materials, collecting data, analyzing the data, drawing conclusions, and the communication of results at various points throughout the year. He held partially formed understandings about questions and questioning, but fully formed beliefs about the other aspects of this premise. His overall understandings remained unchanged over the course of the study.
Roy discussed several times during the year that he believed questions were essential to science. During the first interview he stated, "You have to have a question...you have to have a goal" when beginning scientific research. During the third interview he stated, "You always have to ask a question, then do the science and get an answer." He stated similar beliefs about questions numerous times over the course of the year. However, although he believed that questions were important to the process of science, he did not hold a full understanding regarding questioning because he believed that all questions could be scientific. During the first interview when we were discussing that building a house could be science, our conversation went as follows:

Roy: After I have the materials and the know how then I actually have to start doing it...dig a hole and put in a foundation. Put in rafters and stuff...put on the plywood, build walls, etc...
D: So what's the question?
Roy: How I build the house, what will the house look like?
D: Is that a science question?
Roy: It could be.
D: Are there any questions that are not science?
Roy: What day of the week is it?
D: That's not a science question?
Roy: I don't think so. It might be.
D: Why is it or why isn't it?
Roy: It might not be because it [pause] you don't really have to know much to figure out what day it is, just what day was yesterday. Today is Tuesday...

When we discussed science versus non-science questions during the year he was unsure as to whether there were in fact both of these categories of questions. However, as demonstrated in this dialogue he tended to believe that if you had to "figure something out" then it could be considered a science question. This belief most likely
relates to his notion of science as an organized system of doing some type of activity, as discussed earlier.

Roy and I discussed essential questions concerning his Conservation Biology class during the final interview:

D: What about essential questions for the year? Do they play a big part in this class?
Roy: Oh, I don't really think so...
D: So you didn't use questions every day kind of thing?
Roy: No. No way. We had like maybe a couple of questions here and there. Like we did have a question for each project.
D: Oh you did?
Roy: Yeah, but we didn't answer them. They were just there because it's Valley and you need an essential question. We really didn't stick to the questions like we do in other classes.
D: Could you have done this class without them?
Roy: Yes.
D: It could've worked?
Roy: Yeah. Definitely.

Although he believed that questions were important to science, and even stated that he believed that the class was involved with "real science," he stated that questions were not essential to this class. Perhaps one reason for this is that he believed that Daria directly guided most of what transpired in the class, not essential questions. Like most students he was aware of the general theme of each project, but could not state the questions which supposedly guided the project-based work.

Also like many students, Roy considered the rest of the steps of the scientific method as being very closely related. He described the Conservation Biology class as focusing on data collection activities, including conducting chemical tests on the river and counting the number of macroinvertebrates for the watershed project, and taking the daily water temperature measurements for the salmon restoration project. He had

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hurt his leg during a hiking trip over Valley's spring recess, and was not greatly involved with the outdoor aspects of the Forest Watch project, therefore had little to say about data collection and that project. When discussing data analysis he defined it, in part, as "looking at your data and making conclusions." During the fifth interview he commented that it is better if scientists work together to collect and analyze data because "then they can compare, draw better conclusions once they have a lot of data put together."

Once scientists have drawn conclusions, he believed that they should publish them in "newspapers or scientific journals." Although he generally thought that each project went on "way too long" he did find relevancy in the formal communication aspects which came at the end of each one. He thought writing a letter to the Fish and Game Service and sending data to UNH for the Forest Watch project was important to do, and helped the class be more accurate in doing their work.

He stated that when he considered that other people besides the class might be looking at what they did, he knew "you just couldn't write down any number;" therefore accuracy was important. On the other hand, for the work he did in class that he knew would not be shared with other people, he thought accuracy was not important at all. For example, early in the year Daria had the class make physical models of the river in order to not only foster an understanding of the structure of a river, but to help students begin to understand the uses of models themselves. Roy commented about that activity:

Like I said if we were doing a project to save the river and we needed to know how much water was going through to make the water cleaner or something,
then we need to know exactly how much water there is. So, that's important. But for something like making a shoe box model of what the bottom of the river looks like, it's for a dinky little class in school, so it's not wicked important to get super accurate numbers like down to the gram of water or something.

He stated that even though he wasn't being accurate for this portion of the project, it was still science because they went through "the steps" when doing the work.

"Scientific knowledge demands evidence, and is testable through the scientific enterprise" is the first premise of the model which relates to the nature of scientific knowledge itself. Regarding this premise, Roy's conception was fully formed and unchanging over the course of the year. He discussed at many points throughout the year the notion of "proof" as being necessary for knowledge to be considered scientific. During the fifth interview he concisely stated how one might go about proving such knowledge:

You go through all the studies and do the work and once you get an answer that answers the question, kind of looks like it'll work and if you go through the steps and it will work then it's pretty much proven.

Here he referenced the "steps" which characterized the process of science which he discussed so many times throughout our interviews.

The next premise states, "Scientific knowledge cannot provide complete answers to all questions." Roy developed a fully formed conception of this premise. Early in the year he stated that scientific questions could indeed be fully answered. He provided an example of his position by posing the question, "Is the sun yellow?" and noting that one could look at the sun and make that determination. Toward the end of the year he stated:
It just depends on the question. If it's something simple, then yeah but if it's something really complex and in depth...then you can get an approximate answer but not completely.

His conceptions evolved to consider both simple and more complex questions in science. He still believed that simple questions may be fully answerable, which in many cases may be true, but also came to think that scientific questions may be more complex and difficult, if not impossible to answer. Perhaps because of the way Daria accurately portrayed the project-based work in *Forest Watch* as not being able to determine a definite causal relationship between air pollution and forest health, he came to believe that some scientific questions may not be fully answerable.

The final premise of the model states, "Scientific knowledge is tentative, developmental, and subject to revision." It was difficult to determine Roy's understanding of the tentative nature of knowledge. He commented that things often "change" in science, but we did not extensively discuss this topic.

Regarding the developmental nature of scientific knowledge, Roy stated in the fifth interview that one value of "older knowledge" was that we didn't have to test it again because it was already known. He never discussed knowledge as existing on a continuum in which current knowledge is often a direct outgrowth of older knowledge. His understandings were only partially conceived. Based on our sporadic discussions of both aspects of this premise, his understandings seemed consistent but not fully formed.

The next sub-section will briefly discuss Roy's views of the project-based Conservation Biology class, and the final sub-section will summarize his conceptions.
of the nature of science.

**Conceptions of the Project-based Class** - As stated earlier, Roy enjoyed the Conservation Biology class, stating "The year went well, I thought it was a fun class," but was sometimes critical of it during our interviews. He summed up the essence of what he thought of this class early in the year:

She teaches us something and we go outside and do it...we do projects.

Like many students, he much preferred the "project" aspects of the class over the "she teaches us something" segments. When Daria introduced a new project or reviewed data collection activities, her classes were traditional in nature. They often involved the use of overheads in a lecture format. In contrast, when students actually collected or worked with data, class time was less structured with students interacting and usually working in small groups. Although on one hand Roy liked the hands-on aspects of the class, he only liked those activities in which he was clear on exactly what he was doing. During the activity in which students made physical models of the river, he believed that they didn't need to be accurate because no one was making use of the information but the members of the class. He also had this to say about that activity:

...making the models, that was kind of iffy because she never did it before, and nobody really knew what to do. There's really no guidelines for the project because we're all just making it up as we go...it got confusing at times because we really, there wasn't a set curriculum...like she says, oh go do this, but there's a million ways to do it.

For this activity students worked in small groups and were given the challenge to build a model of the river which runs nearby Valley High. They had a profile graph of
the bottom of the river from which to work. The students decided it would be fun to have a contest of sorts to see which model was the "best." Prior to the construction of the models students could not decide how to define the "best" during a discussion in which Daria inquired how they thought the models should be "judged." Although a few students, including Roy, seemed frustrated with this prior to the construction of the models, many students were upset after the models were built because they were unclear if they did good work.

One key point of this activity was to foster the idea that most times in science there is no "one right answer" and that scientists themselves are left to evaluate the quality of their own work. Daria posed the questions, "What can these models tell us about the river?" "Do you think they are accurate?" and "What are their limitations?" in an attempt to teach about water flow through the river, the use of models, and the process of science which was realistically characterized by both discovery and uncertainty. Although the "debriefing" conversation after the models were built went quite well, in the end Roy and others wanted Daria to decide which model was best for no other reason than "she is the teacher." Roy especially felt frustrated that the teacher ultimately did not hold the "correct" answer. He often looked to her, as many students did, as being the primary source of information and answers in this class. He stated that most of the time "Daria just gives us an assignment and we do it," and he liked that structured environment. Perhaps this is why Roy didn't see questions as being necessary to complete projects in this class; Daria guided the project-based work.
At the end of the year Roy was still very excited about science. He indicated that he was taking two science classes his senior year in addition to what he hoped was "a lot of science classes in college." He still felt that whatever career he chose, "It has got to be outside and it's got to be involved with the environment." He thought he had a lot more to learn about science, but I let him know that he had an excellent foundation upon which to build.

**Summary** - Roy's belief that science could serve as a means by which humans could describe and classify our universe remained unchanged over the course of the year. Similar to several other students, he believed that "everything is science," and never discussed other ways of knowing which might differ from a scientific one. He described the "science" in fixing his car, building a house, and baking cookies. He seemed to confuse the organized, systematic nature of science with science itself.

Roy consistently thought of science as method driven, characterized by a series of steps. He believed science could explain phenomena and compare theories, but only held an incomplete conception of the second premise because he never discussed the predictive nature of science. His beliefs were consistent throughout the study.

Similar to many students, Roy believed that scientists should be imaginative and curious. He also believed that logic or intelligence was important to science. However, he did not discuss serendipity as contributing to the scientific enterprise, therefore his unchanging beliefs were only partially conceived.

Roy's understandings that science is influenced by society/culture were fully formed and consistent throughout this study. He discussed funding issues and societal
problems, such as diseases, as setting the agenda for science. Regarding science as an activity which may be affected by personal factors, Roy's understandings were consistent, yet could not be considered fully formed based on the model. He did not discuss science as a human endeavor.

Based on the final premise of the model which deals with the nature of the scientific enterprise, his understandings were also unchanging. He discussed questions, hypotheses, collecting data, analyzing the data, drawing conclusions, and the communication of results at various points throughout the year. Although he believed that questions were important to the process of science, he also believed that all questions could be scientific resulting in only a partial understanding of this aspect of the premise. He also stated that questions were not essential to the project-based work in Conservation Biology. Perhaps one reason for this is that he believed that Daria directly guided most of what transpired in the class, not essential questions. He held fully formed understandings of the balance of the premise.

Roy discussed the notion of "proof" as being necessary for knowledge to be considered scientific at many points throughout the year. His conception was fully formed and unchanging throughout the study.

Early in the study he stated that scientific questions could be fully answered, however his understandings evolved to consider both simple and more complex questions in science. He still believed that simple questions may be fully answerable, but also came to think that scientific questions may be more complex and difficult, if not impossible to answer. Perhaps his experiences with Forest Watch precipitated this...
shift toward a full conception.

Finally, although he briefly noted that scientific knowledge may change, he did not address the developmental nature of knowledge outlined in this model. Therefore, his understandings which were consistent, were not quite fully developed regarding the final premise.

Tom

Tom was a senior at Valley High and was busy with not only course work and extracurricular activities, but the senior project as well. The focus of his senior project was financial planning, in which he had developed a strong interest in recent years. He explored various aspects of investing, including a critical look at the performance of various stocks and mutual funds. He also had a sincere interest in science. He was an average student based on academic achievement, however his grades had steadily improved over the course of his high school career. He was looking forward to attending college immediately after high school at either his parents' alma matter out west or at a state university in New England. Both schools had various science and business programs, and he wasn't sure which avenue he was going to pursue.

Like most students he had taken Foundations I in ninth grade. His sophomore year he enrolled in biology, and his junior year he took chemistry. During the first interview he commented, "I like to work outdoors, I don't like to sit inside and work out equations." He said that although he did well in chemistry, it didn't interest him because it was only "working with formulas all of the time." Like many students he
looked forward to what he perceived as the hands-on, outdoors nature of Conservation Biology. He seemed to be a dedicated student in class, always ensuring that he completed his assignments on time and frequently participating in class discussions. Toward the end of the year he said he didn't mind working hard on things that he enjoyed, and he enjoyed Conservation Biology.

In addition to Conservation Biology, the focus of Tom's senior seminar was nature. Seminar was a required course for all seniors, and different sections of this class focused on different topics. Among other areas, Tom's seminar course encouraged students to examine the concept of biodiversity from many different perspectives. The course culminated in a biodiversity symposium held at Valley in the spring. During this symposium, students from the seminar presented information to members of the school community. Tom gave a brief presentation on the land use history of the area surrounding Valley. As will be discussed later, this experience afforded him the opportunity to present information in a scientific context.

The first premise of the model states, "The universe is open to human description, classification, and understanding through scientific exploration." Tom's understandings of the universe being open to description and classification through scientific exploration were fully formed and unchanged over the course of the year. However, like many students he believed that there was a "science" to almost everything, and at no point throughout the year did Tom discuss non-scientific ways of knowing in which humans might explore and come to know our universe. His overall conception of this premise was therefore incomplete.
As with other students, the description of his understandings of the second premise, "This scientific exploration attempts to explain and predict phenomena, compare theories, check on previous results, and generate new questions" can provide insight into his beliefs regarding "everything is science."

Early in the first interview, Tom defined science as follows during our discussion:

D: Now, what is science, how would you define science?
Tom: It's hard. Now there is a ton of different sciences to get into. I just think of science as any particular study that involves any, anything with physics and mathematics. It's so broad. I mean, it's hard to really put a tag on it. I don't think [pause] because there is science into everything that you do. Building a bridge, designing a car, studying a frog, or even just when my knee was busted up, there was science going into how to repair my knee...

D: Is there such a thing that is not science?
Tom: I'm not sure. There is political science. Basically you hear how people talk about if Dole won the debate. I don't really know if there are any boundaries, I'm not really sure.

He found it difficult to characterize science, and defined it as relating to mathematics, physics, medicine, biology, engineering, and politics. He was unclear whether there was an area that was not science, and noted that there was a "science into everything that you do." He thought of science as an organized process of doing something.

During the second interview he defined science as "the study of life or particular things," and also went on to note that "it's hard to explain." Later in that interview when I asked how science might differ from other areas, he had difficulty responding to the question:

It's not like writing that is a lot more abstract where you write or read a poem, where you can get so many different thoughts out of it...it's a lot different from math, math is so technical. You can either be right or wrong. In science it's
technical, but not so technical. We know some things about particular organisms, but we don't know others. It's more involved than writing. Writing can be involved, science is figuring out the why of certain things. It's a lot different, you have to be accurate and precise. That's where it is technical.

Here he thought of the process of science as existing somewhere between mathematics and writing, stating that it's technical, but "not so technical." He noted that science searches for the "why" behind things and that accuracy is important. During the third interview, he defined science as follows:

Tom: I just think the definition of science, it's hard. I think it's just basically, it's a study of scientific concepts. Like, I think it's anything...I mean you can't break it down...because science is everything.

D: What about non-science? Is there a distinguishable difference between science and non-science?

Tom: I'm not sure because there's like political science...so it's kind of like a study of certain things and it's hard to really distinguish science from non-science. The only thing I can't think of that's not science is like I think English, basically. Literature really isn't science because there's nothing that's undiscovered I think. So basically anything, it's the study of anything that's not fully discovered. Basically that's what I think of science is. Science can really be anything.

Although he focused his definition around the idea of "discovery," he still had difficulty in differentiating science and non-science. He seemed to think there ought to be a difference, but ultimately described only English, specifically literature, as not being science because there is "nothing that's undiscovered" about it. He struggled with the notion of science and non-science over the entire year, and never seemed quite satisfied with his responses. Later in the interview he went on to discuss that one purpose of science is to compare theories, and noted that sometimes theories are "backed up" and other times they are "shattered" by science.

During the fifth interview some of his beliefs were consistent with prior
discussions, yet his definition seemed to evolve:

Tom: I think of science as it can be many things. Have you ever heard of the term, you can break anything down to a science? I think I've broken down my investments to a science, so I think of science as kind of like not a rhythm but like a mathematical rhythm or a certain pattern rhythm. Like a rhythm of certain sense...the relationships. Think of relationships, anything of any relationship between two or more things. Like investments for example...just to show you how there's a science to everything...

D: So is there an over-arching goal you would say to all of sciences?

Tom: Yeah, I think like first of all science is like basically the study of [pause] the study of anything. I mean it could be anything that you study. It could be like this type of investment science, it could be political science. It's basically the study of cause and effect when you think about it...it's like cause and effect relationships that correlate to break it down to a science and just like what exactly is the effect?

He still believed that "anything could be broken down to a science," once again referring to the organized process of science. During this interview he brought in concepts from his senior project to demonstrate that science deals with patterns and relationships. He specifically discussed "cause and effect relationships."

At this point in the school year Tom, like most seniors, was consumed with his senior project. These projects took a tremendous amount of time and energy on the part of both the seniors and faculty at Valley. I was not surprised to see ideas from his senior project creep into our discussions as they were the talk of the entire school at this point in the year. However, during the sixth interview after the school-wide frenzy surrounding the senior projects died down, he still referred to science as "relationships," and went on to note that science was the study of relationships between "man and Earth."

Tom clarified and expanded his definition of science over the year, but never
seemed fully satisfied with his explanations. His beliefs evolved although he consistently described "everything" as science. He did discuss science as explaining and predicting phenomena, comparing theories, and checking on previous results. However, he didn't describe science as generating new questions, and his overall conception of this premise was incomplete by the end of the year.

The next premise states, "Logic, imagination, curiosity, and serendipity contribute to scientific exploration." Tom's understandings of this premise remained unchanged over the course of the year. He believed that logic, fostered by education, helps scientists develop "expertise" which is important to science. He also stated numerous times that curiosity is also important.

During the third interview Tom stated that imagination is beneficial to the process of science if scientists have:

...the capacity to be able to go forward, be able to look for something that's not found yet, be able to understand what's going on when it's not in the textbook... (if) it's nothing they've seen before.

During the fifth interview he addressed creativity as being important to science when he stated:

You have to be creative...you have to be more open-minded...take a different approach to science all of the time...be able to see that the most common answer isn't always right. That's what creativity is, being able to figure out what that answer really is.

Tom held fully formed understandings of these aspects of the premise, but at no point in the year did we discuss the role that serendipity might play in the scientific enterprise, resulting in an incomplete overall conception.

"Scientific activity is a social activity conducted by individuals who are
influenced by both cultural and personal factors" is the next premise of the model. Tom's understandings of this premise remained unchanged throughout the study, in fact his beliefs were remarkably "real world" concerning these areas right from the beginning of the year. In part, he developed these beliefs by speaking with his older brother, an engineer, who had often discussed his job with him. Tom understood science as a social activity which is influenced by societal needs and wants, and is often driven by both governmental and private funding. He noted automobile companies developing electrical cars and pharmaceutical companies "trying to find a cure for AIDS and cancers" as being science. He described science as not being "pure," believing that "it all comes down to money." He noted:

There is a lot of money involved. My brother used to be a chemical engineer at Exxon. If they figure out a new way to drill oil out in the ocean, do you think they will share it with Sunoco? I don't think so...science is now starting to become big bucks. More and more advanced we become as people the more and more we need certain things. I think science is playing a huge role.

He also discussed the defense industry several times over the course of the year. He noted that during the Cold War there was a need to conduct research and develop new planes and weapons, but now with a perceived lessened need for those items people view those large expenditures as not necessary.

He also discussed the salmon restoration project with regard to this aspect of the premise. He stated that although the Fish and Game Service could run the entire New England restoration project for only hundreds of thousands of dollars, they are struggling for funding. He noted that compared to the cost of one fighter jet the budget for this program was small. He felt that the reason they are struggling for funding is
because people didn't view the Atlantic salmon as a "poster species," stating it's "not like the panda." He said that if people thought that salmon were cute, the program would be well funded. This statement demonstrates his belief that society can influence science, and that what is "scientifically important" is not what is always supported by society.

Tom also held fully formed, unchanging understandings about science as an activity influenced by personal factors. He thought of science as a human activity in which scientists themselves may have an impact on the outcome of their work:

I think results are also different because of perspective...also what people think is going to come out of it also kind of sways the results. Like if they're disappointed because something didn't happen, or they're happy because it did happen.

In this passage he discussed scientists as potentially being biased, but perhaps more importantly that science can be influenced by this "personal factor."

The final premise of the model which deals with the nature of the scientific enterprise states, "Questioning, data collection and analysis, drawing of conclusions, and communication are the major phases which characterize the scientific endeavor."

Like most participants, Tom noted that he could not remember all of the steps in the correct order. However, he did describe questions, hypotheses, experiments and controls, and conclusions as being characteristic of the scientific method. He pointed out that depending on the topic for study, the method might need to be altered slightly to investigate that particular subject. He did not think of the scientific method as a fixed set of steps that someone would blindly follow. His partial conception of this premise did not change over the course of the year.
From the very first interview Tom believed questions were critical to science. He noted that when someone becomes interested in an area, "they start to ask questions" and that allows them to examine an area further. However, considering his beliefs that "everything is science," perhaps it is not surprising that he believed that all questions could be scientific in nature. At no point in the year was he able to articulate or describe a non-science question, resulting in only a partially conceived understanding of this aspect of the premise.

Like other students Tom noted that questions in the Conservation Biology class were provided for them. He stated, "You can always pose your own questions after class, but basically it's a class effort and you are supposed to work in groups." He noted that he developed his own question for senior project and was encouraged to pursue it. He stated, "It is supposed to be your whole focus of one thing" which is why they worked for senior project. He thought essential questions were too limiting for Conservation Biology:

That's the only thing I didn't like about Valley, it had too many damn essential questions. I don't think they mean that much...I don't think essential questions are really great. When you have an essential question it makes you geared toward another part of a project. Instead of looking at something that is more interesting you have to look at that because it's the essential question. You have to answer it or you don't pass. An essential question is kind of stupid, well not stupid but they don't work.

Although on one hand he believed questions were important to science, on the other he came to resent essential questions at Valley stating that they didn't work, perhaps because they were over utilized, limiting, and usually prescribed.

He thought accuracy was the most important element of data collection. Tom
noted several times during the year, as did several students, that Daria said, "You can only be as accurate as your least accurate measurement." He thought that when the class participated in data collection activities for the various projects being accurate was the main goal, and explained that they practiced data collection techniques in order to ensure accuracy. He thought that data analysis and formulating conclusions were closely tied, and together related to data collection. He stated the data analysis was "looking at your data." Referring to the river project he noted that you have to not only look at the data itself, but see which collection site it came from because that might have an impact on your results. This belief demonstrates that he understood there was a close relationship between these phases of the scientific enterprise. His understandings of data collection, analysis, and drawing of conclusions were unchanging and fully formed over the study.

We rarely discussed the communication of results over the course of the year. However, during the first interview he noted that scientists might not always share their findings. Once again he cited money as a factor which might influence science and preclude scientists from communicating their results. He noted that he and other students in the class had ample opportunity to discuss their project-based work in class, and that he liked this informal communication. He felt that the class did a lot of group work, but felt that was the norm for Valley.

Toward the end of the watershed project, each small group in the class had the opportunity to formally present information regarding the various parameters of the river which they studied. For example, one group discussed the river pH, while
another presented on turbidity. Each group summarized the data collection techniques and presented what amounted to "raw data." Each group, including Tom's, seemed to struggle with presenting scientific "conclusions." Tom noted that they did a lot of presenting at Valley, and he did not seem to give it much thought. Group work and discussion, and presenting project work all seemed commonplace at Valley. His experiences in Conservation Biology regarding communication in science did not seem to contribute to his partial understandings of this aspect of the premise.

Tom presented at the biodiversity symposium late in the year. This symposium was somewhat modelled after a scientific conference. It began with a keynote speaker from UNH who introduced and addressed various aspects of biodiversity. Following, each student or group of students presented information relating to that topic. Tom had the opportunity to discuss the land use history of the Valley area. This had important implications regarding scientific work, including the Forest Watch project, which was done within the vicinity of the school. About a week later when I discussed this symposium with Tom, he said he did not prepare much for the talk, and hadn't really thought much about it. He stated he was too busy with senior project to worry about it. Once again, it did not seem to mean a great deal to him nor have much of an impact on his partial understandings, which remained consistent throughout the study.

The first premise of the model which relates to the nature of scientific knowledge states, "Scientific knowledge demands evidence, and is testable through the scientific enterprise." Tom's conception was fully formed and unchanging. During the second interview he discussed the notion of "proof" as being necessary to support
scientific information. He stated scientific information, "...has to be proved. You can't just say deer run away before we can see them therefore they must have really good hearing. Maybe they can smell you." He believed an "experiment" was the best way to definitively prove or not disprove something.

For the next premise, "Scientific knowledge cannot provide complete answers to all questions," he also held a fully formed, unchanging conception for the duration of the study. He stated, "Sometimes (questions) can, most times they can't (be fully answered)," referring to this premise. He especially believed questions would be difficult to answer when they are predictive in nature. Regarding the watershed project he stated, "We came up with a hard time finding out what would happen to a river in 30 years." He thought that the class could answer the question of "What will the river look like in 30 years?" by providing some possibilities, but not complete answers.

The final premise of the model states, "Scientific knowledge is tentative, developmental, and subject to revision." Tom's understandings of this premise were also fully formed and unchanging over the course of the year. He discussed scientific theories as being only a current understanding of a scientific phenomena, and that our understanding could change with time. He believed scientific knowledge is developmental. He used our understanding of comets as an example:

A hundred years later people could know a lot more about a comet...the little steps you learn change your whole picture because you find out that it's not what you think it is.

He noted that one must always go back to "old knowledge" because it can be "re-applied in different ways."
The next sub-section will briefly discuss Tom's views of the project-based Conservation Biology class itself, and the following sub-section will summarize his conceptions of the nature of science.

Conceptions of the Project-based Class - Tom enjoyed the Conservation Biology class tremendously. Like most students, he had great respect for Daria and her sincere love of nature. He stated about midway through the year that one purpose of this class was to foster an awareness of environmental issues in students. He said the class certainly did that for him and cited various water pollution problems, especially thermal pollution, as something that he now felt strongly about but simply wasn't aware of before taking the class. He commented that he has a greater respect for nature than he did prior to taking Conservation Biology.

Tom stated that he had forgotten many things from previous classes, but said that he found this year "more interesting" than most science classes he had taken, and expected to remember more of it. Part of the reason he liked this class was because of the hands-on nature of it. He thought actually collecting data made it more like real science. However, during the fifth interview I asked him if there were any differences between real science and school science, and he responded:

Oh, yeah...high school's more of a stepping stone to real life and going into college and college science will get more advanced because really you're dealing with more complex equations, more complex type of sciences. I mean, it often depends but at the same time usually real world science is harder because they really expect you, they put pressure on you to like perform.

Although the partnership with scientists in the various projects made the course more real for Tom, and contributed to the class being accurate in their work, he still felt that
there were differences between real science and school science. First, he noted that the questions would be more complex in real science, and second he believed that scientists are most likely under more pressure to "perform." He believed that the project-based work in the class wasn't necessarily real science, but perhaps only a small part of it. He thought the work would have to be more complex in order for it to be considered "real." He did not see their data or results as actually contributing to scientific studies, even though they were. He simply didn't believe a high school could participate in the scientific endeavor. He thought college was the minimum level in which that could occur. He assumed there must be "more to it" in order for it to be considered science.

Tom was accepted into several colleges, including his parents' alma matter and several New England schools. By the end of the year he was still not sure which avenue, business or science, that he wished to pursue. He had a positive experience with both his senior project and with the Conservation Biology class. He stated that he needed to "reflect" a bit more on it, and might select a school which would give him both opportunities. However, toward the end of the year he stated:

Like I don't know, maybe biology is my calling. I don't know...people sometimes smirk at science because it's pretty dry, boring and dull, but I think it can be very exciting because it's something, you're taking knowledge that you've never had before and you're transforming it into new knowledge for the entire world. So that'd be great. That's an honor to do.

Summary - Concerning the first premise, Tom's conception was partially formed and unchanged over the course of the year. Like many students he believed that there was a "science" to almost everything, and at no point throughout the year
did he discuss non-scientific ways of knowing in which humans might explore and come to know our universe. However, he did hold a full understanding that science could describe and classify the universe.

Regarding the second premise, early in the year he thought of science as an organized process of doing something. Although he held this general belief later in the year, he adopted the notions of "discovery" and "patterns and relationships" as being characteristic of science. He had difficulty in distinguishing between science and non-science. He seemed to think there ought to be a difference, but struggled with the notions of science and non-science over the entire year, and never seemed quite satisfied with his explanations. He clarified and expanded his descriptions throughout the year as he searched for a clearer and improved definition, but ultimately only held a partial conception of this premise.

Tom held full understandings about the role of logic, imagination, and curiosity, however at no point in the year did we discuss the role that serendipity might play in the scientific enterprise. His overall conception was therefore incomplete.

Tom held a fully formed conception of science as a social activity influenced by both cultural/societal and personal factors. These beliefs remained unchanged over the course of the study. He understood science as an activity influenced by societal needs, and one that is often driven by both governmental and private funding. He noted that his older brother, an engineer, had often discussed this issue. Tom also thought of science as a human activity in which scientists themselves may have an
impact on the outcome of their work.

Tom did not think of the scientific method as a fixed set of steps that someone would blindly follow. He believed questions were important to science, even though he believed essential questions were too limiting for work in the Conservation Biology class. He thought of presenting as typical of many classes at Valley, and his experiences did not necessarily contribute to his understandings of communication in science. He held fully formed understandings of data collection, analysis, and making conclusions, but only partial understandings of questions and communication.

Regarding all premises which constitute the nature of scientific knowledge, his conceptions were fully formed and unchanging over the course of the study. He discussed the notion of proof as being important to scientific knowledge. He felt that most scientific questions could not be fully answered, especially predictive ones. Finally, he believed scientific knowledge to be developmental and tentative in nature.

Valley Summary

As discussed in the Woodland Summary at the end of Chapter IV, although many studies have found student conceptions of the nature of science to be poor (Lederman, 1992; Meichtry, 1993), findings from this research are to the contrary. By the end of the year, participants at Valley exhibited fully formed conceptions of the nature of science approximately 40 percent of the time based on the premises of the model developed and utilized for this study. However, participants held full understandings for various aspects of those premises approximately two-thirds of the
time, even if their overall conception of the premise was only partially formed. In approximately three-quarters of the cases, whether fully or partially formed, participants' beliefs were unchanging throughout the study.

It is important to note that even when understandings were found to be fully formed based on the model used in this study, it does not preclude room for growth. In fact, AAAS (1989) describes scientific literacy as a life long process, therefore an understanding of the nature of science, which is a principal component of developing scientific literacy, should also be viewed as an ongoing endeavor.

Based on the first premise of the model, as with Woodland, all participants held fully formed, unchanging understandings regarding the universe being open to human description and classification. However, no participants distinguished science as one way of knowing, resulting in only incomplete conceptions for the overall premise. All participants except for Heather held the belief that "everything is science." Although Lisa believed that we think of science "unconsciously," the remaining students thought that any activity characterized by an ordered process is scientific.

The next premise essentially defines science, and all participants held only partially conceived conceptions. Only Roy's beliefs of all aspects of this premise remained unchanged. Dorothy made use of vocabulary which was characteristic of science when attempting to define it, but was unable to sufficiently explain the meaning of most terms.

All participants held incomplete conceptions of the next premise which discusses logic, imagination, curiosity, and serendipity and their relationship to
science. No participants at Valley addressed serendipity as being important to science. All participants' understandings remained unchanged over the course of the year.

The next premise describes the scientific enterprise as an activity which is influenced by societal/cultural and personal factors. Heather, Roy, and Tom held fully formed understandings of science as an activity influenced by society. Tom's understandings were exceptionally "real world." He viewed science as driven by funding, often competitive, and greatly influenced by societal needs. Lisa and Roy were the only participants who held partially conceived understandings of science as a human endeavor. That is, they did not cite scientists themselves as being an integral part of the process of science. All participants' understandings were consistent throughout the study for both aspects of this premise.

The next premise addresses the phases which characterize the scientific enterprise, more commonly known as the scientific method. Heather and Lisa held fully formed, unchanging conceptions of this premise. Dorothy, Roy, and Tom held only partially conceived understandings. Participants were generally unable to recite the essential questions which supposedly guided the class's project-based work, although most thought questions were important to science. In addition, they noted that questions were provided for the class except on rare occasions as in the salmon study. All students described data collection and analysis activities as comprising the bulk of the year's work. They expressed accuracy as being important when conducting these activities.

Except for Dorothy, all participants held fully formed conceptions of the first
premise of the model which specifically dealt with the nature of scientific knowledge. Only Heather consistently held a partially conceived conception of the next premise. She believed that scientific questions could be fully answered. Roy developed a fully formed conception, coming to believe that scientific questions could be both simple and complex. His work with Forest Watch may have precipitated this change. Finally, Heather and Roy held partial conceptions concerning the developmental, tentative nature of scientific knowledge. Lisa developed fully formed conceptions, and came to understand the developmental nature of knowledge over the course of the year. Her work with technology over the year may have contributed to this shift.

Themes

There are several predominant themes which have arisen from the work at Valley. Like at Woodland, these important points will be briefly summarized here and discussed in detail in Chapter VI. The nature of this qualitative study and the ability to reliably describe student conceptions of the nature of science, and most participants' belief that "everything is science," were two important points supported by the work at both Woodland and Valley, and will be discussed in the next chapter. However, as discussed earlier I believe the strongest aspect of this body of work lies within the richness of the descriptions themselves because a more complete understanding of participants' conceptions can be acquired by directly reading students' beliefs in their own words.

Another similar theme which arose at Woodland and was also seen at Valley
was the involvement of essential questions. Participants at Valley were unable to recite the essential questions which supposedly guided the class's project-based work, although most students thought questions were important to science. Unlike at Woodland where students who worked on individual projects made use of questions to complete their project work, students at Valley hardly made use of questions at all when they pursued their class projects. They noted that for the most part questions were provided for the class, except on rare occasions, so perhaps they did not have ownership over them. As Roy mentioned, Daria, not the essential questions, guided the activities in class from day to day. Without the questions serving as a common thread throughout the projects, students sometimes viewed their project-based work as merely a series of disconnected activities.

Student conceptions of real science versus school science is also another important theme. Although the SSP aspect of the class brought relevancy for many students, feeling it was important to be a part of "something larger" and share data with scientists, they still thought of school science as fundamentally different from real science. Tom believed that even though the class was participating in SSPs, such as the Forest Watch program with UNH, he believed "real science" must still be more complex. He stated that he didn't believe high school students could actually participate in real science. Although organizations such as the NRC (1996) advocate that students participate in real science, and the Conservation Biology class in fact does, it seems some students feel that they aren't. Determining ways in which we can take the "school" out of school science and make it explicit to students that what they
are doing is authentic is an important task for science educators, especially if they advocate participating in real science as a vehicle to science reform.

Another theme which arose from this research site was the notion of time, more precisely a lack of large uninterrupted blocks in which to pursue project-based work. Although this was also a factor at Woodland, the senior projects at Valley greatly impacted student time. Although there are many benefits of a culminating project such as this, Tom in particular seemed to focus his attention toward the senior project for a significant portion of the year in order to complete it. Within the Conservation Biology class, Daria felt that teaching in a project-based manner was very time consuming and found it difficult to carve out portions of the year to focus various aspects of the project work. Even when only attempting several large projects over the course of the year and focusing on few concepts, it was difficult for the class to make progress at many points. Although Roy believed the projects dragged on, Daria constantly felt the year was hectic and that time slipped by too fast.

Finally, it is important to note that as at Woodland, participants at Valley also held conceptions of the nature of science which rarely changed over the course of the year. In Chapter VI, reasons for why certain conceptions changed and why in some cases it is difficult to determine exactly what may have effected participants' beliefs will be discussed. Like Woodland, students were undoubtedly influenced by factors other than those in the project-based class, and certainly ones outside the realm of formal schooling altogether.
CHAPTER VI

DISCUSSION AND IMPLICATIONS

This study examined the central question, "What conceptions of the nature of science do precollege students hold and develop over the course of an academic year?" Additionally, this work explored how project-based teaching models may have affected students' conceptual development. This study finds that by the end of the year participants at both classroom sites held fully formed conceptions of the nature of science for approximately 40 percent of the premises across the model. Generally, students held more complete understandings of the nature of scientific knowledge than the nature of the scientific enterprise. For example, few participants explained that the process of science generates new questions for scientific study or appreciated the role of serendipity in science, however most participants understood that knowledge requires evidence or "proof" in order to be considered scientific, and that scientific knowledge is tentative and developmental in nature.

Overall, participants' conceptions of the nature of science remained unchanged over the year for approximately three-quarters of the premises. Students at both classroom sites began the year with either partial or full understandings of many premises, and their beliefs remained consistent throughout the study. Regardless of whether participants' overall conceptions of a premise were fully formed, for nearly two-thirds of the elements which comprise the premises, participants held full understandings (see tables 2 & 3). These findings indicate that students' beliefs may

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Table 2. Summary of Participant Conceptions of the Nature of Science at the end of the year from Woodland High School.

<table>
<thead>
<tr>
<th>Elements of each premise in model</th>
<th>Ben</th>
<th>Bryan</th>
<th>Donna</th>
<th>Linda</th>
<th>Larry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Universe open to exploration</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
</tr>
<tr>
<td>Science is one way of knowing</td>
<td>Partial</td>
<td>Partial</td>
<td>Partial</td>
<td>Partial</td>
<td>Full</td>
</tr>
<tr>
<td>Science explains phenomena</td>
<td>Full</td>
<td>Partial*</td>
<td>Full</td>
<td>Full</td>
<td>Full*</td>
</tr>
<tr>
<td>Science predicts phenomena</td>
<td>Partial</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>Full</td>
</tr>
<tr>
<td>Science compares theories</td>
<td>Full</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Science checks on results</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>Partial</td>
<td>None</td>
</tr>
<tr>
<td>Science generates questions</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Logic advances science</td>
<td>Full</td>
<td>Partial</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
</tr>
<tr>
<td>Imagination advances science</td>
<td>Full</td>
<td>None</td>
<td>Full</td>
<td>Full*</td>
<td>Full</td>
</tr>
<tr>
<td>Curiosity advances science</td>
<td>Full</td>
<td>None</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
</tr>
<tr>
<td>Serendipity advances science</td>
<td>None</td>
<td>None</td>
<td>Full</td>
<td>Full*</td>
<td>Full</td>
</tr>
<tr>
<td>Science is social/cultural</td>
<td>Full</td>
<td>Full</td>
<td>Full*</td>
<td>Partial</td>
<td>Full*</td>
</tr>
<tr>
<td>Personal factors affect science</td>
<td>Partial</td>
<td>Full</td>
<td>Partial</td>
<td>Partial</td>
<td>Full</td>
</tr>
<tr>
<td>Questioning</td>
<td>Partial*</td>
<td>Partial</td>
<td>Partial</td>
<td>None</td>
<td>Full</td>
</tr>
<tr>
<td>Data collection</td>
<td>Full</td>
<td>Full</td>
<td>Partial</td>
<td>Partial*</td>
<td>Full</td>
</tr>
<tr>
<td>Data Analysis</td>
<td>Full</td>
<td>Full</td>
<td>Partial</td>
<td>Partial</td>
<td>Full</td>
</tr>
<tr>
<td>Drawing of conclusions</td>
<td>Full</td>
<td>Full</td>
<td>Partial</td>
<td>Partial</td>
<td>Full</td>
</tr>
<tr>
<td>Communication</td>
<td>Full</td>
<td>Full*</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
</tr>
<tr>
<td>Knowledge requires evidence</td>
<td>Partial*</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
</tr>
<tr>
<td>Knowledge is testable</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
</tr>
<tr>
<td>Not provide complete answers</td>
<td>Full</td>
<td>Full</td>
<td>no data</td>
<td>Partial*</td>
<td>Full</td>
</tr>
<tr>
<td>Knowledge is tentative</td>
<td>Full</td>
<td>Partial*</td>
<td>Partial*</td>
<td>Full</td>
<td>Full</td>
</tr>
<tr>
<td>Knowledge is developmental</td>
<td>Full</td>
<td>None</td>
<td>Partial*</td>
<td>Full</td>
<td>Full</td>
</tr>
</tbody>
</table>

None = did not address element of model; Partial = conception partially formed; Full = conception fully formed; * = conception evolved over course of the study. Note participant must hold a full understanding of each element of a premise for conception of that premise to be fully formed.
Table 3. Summary of Participant Conceptions of the Nature of Science at the end of the year from Valley High School.

<table>
<thead>
<tr>
<th>Elements of each premise in model</th>
<th>Heather</th>
<th>Dorothy</th>
<th>Lisa</th>
<th>Roy</th>
<th>Tom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Universe open to exploration</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
</tr>
<tr>
<td>Science is one way of knowing</td>
<td>None</td>
<td>Partial</td>
<td>Partial</td>
<td>Partial</td>
<td>Partial</td>
</tr>
<tr>
<td>Science explains phenomena</td>
<td>Full*</td>
<td>Partial*</td>
<td>Full*</td>
<td>Full</td>
<td>Partial*</td>
</tr>
<tr>
<td>Science predicts phenomena</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>Partial</td>
</tr>
<tr>
<td>Science compares theories</td>
<td>Full</td>
<td>None</td>
<td>None</td>
<td>Full</td>
<td>Partial</td>
</tr>
<tr>
<td>Science checks on results</td>
<td>Partial</td>
<td>None</td>
<td>Partial</td>
<td>None</td>
<td>Partial</td>
</tr>
<tr>
<td>Science generates questions</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Logic advances science</td>
<td>Full</td>
<td>None</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
</tr>
<tr>
<td>Imagination advances science</td>
<td>Full</td>
<td>None</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
</tr>
<tr>
<td>Curiosity advances science</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
<td>Fill</td>
</tr>
<tr>
<td>Serendipity advances science</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Science is social/cultural</td>
<td>Full</td>
<td>Partial</td>
<td>Partial</td>
<td>Full</td>
<td>Full</td>
</tr>
<tr>
<td>Personal factors affect science</td>
<td>Full</td>
<td>Full</td>
<td>Partial</td>
<td>Partial</td>
<td>Full</td>
</tr>
<tr>
<td>Questioning</td>
<td>Full</td>
<td>Partial</td>
<td>Full</td>
<td>Partial</td>
<td>Partial</td>
</tr>
<tr>
<td>Data collection</td>
<td>Full</td>
<td>Partial</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
</tr>
<tr>
<td>Data Analysis</td>
<td>Full</td>
<td>Partial</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
</tr>
<tr>
<td>Drawing of conclusions</td>
<td>Full</td>
<td>Partial</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
</tr>
<tr>
<td>Communication</td>
<td>Full</td>
<td>Partial</td>
<td>Full</td>
<td>Full</td>
<td>Partial</td>
</tr>
<tr>
<td>Knowledge requires evidence</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
</tr>
<tr>
<td>Knowledge is testable</td>
<td>Full</td>
<td>Partial</td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
</tr>
<tr>
<td>Not provide complete answers</td>
<td>Partial</td>
<td>Full</td>
<td>Full*</td>
<td>Full*</td>
<td>Full</td>
</tr>
<tr>
<td>Knowledge is tentative</td>
<td>Partial</td>
<td>Full</td>
<td>Full*</td>
<td>Partial</td>
<td>Full</td>
</tr>
<tr>
<td>Knowledge is developmental</td>
<td>Full</td>
<td>Full</td>
<td>Full*</td>
<td>Partial</td>
<td>Full</td>
</tr>
</tbody>
</table>

None = did not address element of model; Partial = conception partially formed; Full = conception fully formed; * = conception evolved over course of the study. Note participant must hold a full understanding of each element of a premise for conception of that premise to be fully formed.
not be as poor as outlined in previous studies which conclude that students exhibit inadequate understandings of the nature of science (Clough, 1997; Lederman, 1992; Meichtry, 1993; and Ryan & Aikenhead, 1992).

**Qualitative Methodology**

The current study demonstrates that qualitative methodologies, especially formal interviewing in combination with participant observation, are effective at uncovering, identifying, and understanding students' conceptions of the nature of science which they bring to and develop in learning environments. Lederman and colleagues (1997) state that the significant question regarding an individual's conception of the nature of science should center around the limits of one's understandings. The current study illustrated the limits of students' understandings through the rich descriptions presented in Chapters IV and V.

The frequent interaction with participants, both formally through interviews and informally in the classroom setting, resulted in a fuller characterization and description of actual conceptions than might be accomplished through a short duration, often one-time quantitative study. In fact, in a number of instances it would have been impossible to characterize participant beliefs accurately without the benefit of long term interaction and dialogue. For example, at Woodland Donna was only able to list several of the steps which characterized the scientific method during our formal interviews. At no point did she discuss the scientific method in a complete manner in this structured setting. During these interviews she focused on listing the steps in the
"correct" order and became flustered and frustrated when she had difficulty remembering them. However, in this study I characterized Donna's conceptions of the scientific method as mostly developed, not based on the transcripts from the formal interviews, but based on my notes from our frequent, informal interactions in class. During the classroom setting perhaps she felt less "on the spot," and when I posed questions about the scientific method she was able to discuss the various steps and their importance to science.

In contrast, Dorothy at Valley was able to readily list the steps of the scientific method during our formal interviews, and at one point was even able to give a basic definition of a hypothesis in a scientific context. However, even though she was able to recite the vocabulary indicative of the process of science, it was clear through follow-up questions, in both formal and informal interviews, that she only held rudimentary understandings of this premise. These examples highlight how the research design of this study, especially ongoing classroom interactions with students throughout the year, permitted a fuller description and understanding of their beliefs.

Using data acquired through a multiple choice instrument, titled Views on Science-Technology-Society (VOSTS), Ryan and Aikenhead (1992) report that 19 percent of students (N > 2000) in grades 11 and 12 characterize science as undefinable. In this study, there were no participants who characterized science as undefinable at any point throughout the year. Although students sometimes held very broad or narrow understandings of science which were incomplete, they at least held some conception, and the current study was able to uncover and report on those
beliefs. After reviewing the vast quantitatively oriented studies dealing with the nature of science, Lederman et al. (1997) conclude, "We have taken paper and pencil assessments about as far as they can be expected to go" (p. 27). He supports using a variety of methodologies to assess individual's understandings of the nature of science. This study supports their position that qualitative studies can significantly add to our knowledge base of students' beliefs of the nature of science.

Specifically, a qualitative approach affords one the opportunity to ask questions designed to solicit student conceptions in a number of ways to ensure that students understand what you are asking them. Griffiths and Barry (1993) note that a limitation of quantitative research, such as a survey instrument, is that there is a chance that students might not attach the same meaning to items as the test developers, perhaps resulting in a misinterpretation of a question. In this study, for example, in addition to simply asking participants to define science to solicit their understandings about the second premise of the model, I asked them what they believe the overall goal of science should be and why they believe science is important. I was able to elicit the same basic information in a number of ways and immediately follow-up if students were unclear about a question by asking, "What do you mean by that?" and "That sounds interesting, why do you think that?" Probing for participant beliefs via a long-term qualitative approach resulted in rich, descriptive accounts of their conceptions.

Ausubel (1968) underscores the importance of knowing students' conceptions, believing that the most important factor influencing learning is what the learner already knows. Even if students hold alternative conceptions, notions that are
inconsistent with explanations offered by scientists and science teachers (Hewson, 1981), it is critical that educators are aware of students' beliefs. When science teachers are cognizant of students' beliefs, they can better tailor science instruction to facilitate the restructuring of students' knowledge. This restructuring is necessary for learning to take place according to conceptual change theory (Posner, et al., 1982).

**Conceptual Change and Student Conceptions**

At both classroom sites, the majority of participants' conceptions of the nature of the scientific enterprise and the nature of scientific knowledge remained unchanged over the year. Students typically began the year with fully formed or partially conceived beliefs, and little change was seen in their understandings throughout the study. However, in certain cases, when participants' conceptions evolved it was possible to relate that change to the experiences they received in the project-based classes, although at other times it was difficult or impossible to speculate any cause for change. For example, Bryan from Woodland developed a fully formed understanding of communication over the course of the year, coming to believe that communication in science was extremely important. The Project Seafarer curriculum emphasizes the importance of communication by requiring students to present their work and attend and critique their classmates' presentations. These presentations were the primary means of assessment in this class, and a great deal of time was spent addressing this area. Perhaps because communication was so heavily emphasized, Bryan's conceptions evolved in this area. A more detailed discussion of additional
elements of the project-based models which likely contributed to a change in participants' beliefs is presented in a later section.

There were instances in this study in which it was not possible, at least in any obvious way, to associate changes in students' understandings with any known experiences they received. For example, Lisa from Valley believed at the beginning of the year that scientific questions could not be answered fully, but by the end of the year thought that sometimes they could. Donna, from Woodland, came to believe late in the year that in addition to a scientist's individual curiosity, society will have an influence over what he or she studies. Were these changes precipitated by factors related to the project-based classes? Did experiences they received outside of class lead to these changes? There are no data which suggest reasons for the evolution of their beliefs, and these questions are left unanswered. Even in work such as this in which descriptions of student understandings and experiences are detailed, it is not possible to know participants' precise mental processes which may have contributed to a change in their belief structures.

How learners change their knowledge structure in a science setting is an important area for research (Good, in press). Conceptual change has been proposed as one mechanism by which learners construct meaning in science classroom settings (Linder, 1993; Posner et al., 1982; Southerland, 1997). It is a constructivist model (Treagust et al., 1997), implying that an active learner makes connections between experiences in an attempt to understand our world. In early work, Posner et al. (1982) described their conceptual change theory as explaining the methods by which
conceptual frameworks are constructed and modified, such as when a learner captures new concepts or restructures existing concepts. This theory usually deals with key or central concepts, such as the nature of science, and explains that conceptual change occurs when learners recognize shortcomings in their current understandings and discover or are shown a more plausible, intelligible alternative. In this model, older concepts are often completely replaced by newer ones.

Most participants, including Tom from Valley, held the conception that "everything is science" over the course of the study, having difficulty in distinguishing between science and non-science. Tom thought science was primarily characterized by an organized process. He seemed to think there ought to be a clear difference between science and non-science, but ultimately described only English as not being science because there is "nothing that's undiscovered" about it. He struggled with the notion of science and non-science over the entire year, and was dissatisfied and frustrated with his explanations of the differences that he provided during our interviews. That is, this learner recognized shortcomings in his current understandings, but was never shown a more plausible, intelligible alternative to his beliefs. He tried to discover his own alternative model of science, which was evident as he clarified and expanded his descriptions over the course of the year, but never quite achieved a clear understanding of the distinction between science and non-science. For this reason, his older conception was not replaced by a newer one and he still held the belief that everything is science at the end of the year, knowing "it wasn't quite right." The model of conceptual change as described by Posner and colleagues, especially the precondition
of a learner being dissatisfied with his or her current understandings, was clearly evident in this case. Perhaps, if an alternative model had been made available to this learner his conception of the nature of science would have matured.

Building upon the work of Posner et al. (1982), Southerland (1997) concludes conceptual change is neither simplistic nor linear. She describes several models of conceptual change and refers to them as patterns, one of which she labels incremental change. In incremental changes, the learner employs new terms within a previously constructed explanation. She notes this often reflects a lack of a full, scientific understanding, and that conceptual change is not complete. An example of this may be seen in Dorothy's conceptions of the second premise of the model which outlines phases of the scientific enterprise. As noted, this premise served as essentially a definition of science. Dorothy stated that science "made comparisons" and was involved with "evaluating things" early in the year. Later in the year, she defined science as "involving facts, scientific proof, a theory about some scientific meaning." When I asked her if there was a general goal to all of science, she responded, "I think it's trying to figure out how it works, how something works." Although Dorothy's definitions of science changed somewhat over the course of the year, her conception of this premise remained partially formed. She seemed to make use of vocabulary which is descriptive of science, such as "theory," but was not able to explain what she meant by her statements. She had a general view of science over the course of the year which centered around the notion of "proving something," but merely brought in new terms to enforce this belief.
In addition to describing incremental changes, Southerland (1997) describes "dual conceptions" as a model of conceptual change which exists when a learner holds and applies two logically incompatible conceptions for the same phenomena. This occurred with Lisa at Valley who believed that questions were important to science, but not necessarily to her project-based science work in Conservation Biology. This belief persisted even though she described the class as scientific in nature. Lisa and her classmates completed the bulk of the project-based work, which was data collection and some analysis, without consistently revisiting or considering their initial research questions. Scientific questions and questioning were not emphasized by the teacher, they were only discussed at the beginning and end of each project. It is probable that through earlier instruction Lisa came to believe that questions were essential to science. Had she experienced a consistent revisiting of questions throughout each project, she may have had her previously established beliefs confirmed through her class experiences.

This example highlights an important point concerning the previous conceptions that students bring to a learning setting. Naizer (1997) notes that these conceptions do not necessarily develop in classrooms, but can develop in the home and community. Certainly, Tom from Valley who held fully formed understandings of science as a social activity developed many of these ideas not through school, but by talking to his older brother who was an engineer, and by watching television. Many participants reported watching science related television programs and/or reading magazines and books which incorporated scientific ideas. Larry from Woodland
developed his beliefs about gender and science in part based on his tumultuous relationship with his girlfriend. Southerland (1997) argues for an expanded role of the learner's prior knowledge, including deeply held, culturally and experientially influenced understandings if we are to truly model and understand a broad range of science learning. The current study strongly supports that idea, emphasizing that learning in science occurs throughout many aspects of students' lives beyond the science classroom.

The Tentative Nature of Scientific Knowledge

Results from this study indicate that participants generally held fully formed notions of the nature of scientific knowledge, including the tentative and developmental nature of knowledge, but were less sure of the nature of the scientific enterprise. The Nature of Scientific Knowledge Scale (NSKS) is an instrument developed to assess precollege student understandings of the nature of scientific knowledge. Using the NSKS, Rubba (1977) concluded that 30 percent of the students at a large midwestern high school believed that scientific research leads to knowledge which is incontrovertible, absolute truth. Reporting on results from a follow-up study using that instrument, Meichtry (1993) states, "Students did not understand the nature of science well enough to appreciate the tentative nature of scientific knowledge" (p. 435). Findings of the current study are not consistent with Meichtry. In the current study, most participants held full conceptions of the premise which characterizes scientific knowledge as tentative, developmental, and subject to revision. The
remainder of the participants held at least a partial conception of this area, even if their ideas were not fully formed.

For example, Heather often mentioned "theories" when discussing science. She defined a theory as "a hypothesis that has been tested again and again." She noted that a theory could potentially lead to a "fact" if, like a hypothesis to a theory, it was tested. She viewed hypotheses, theories, and ultimately scientific facts as existing on a continuum based on the amount of evidence there is to support each level of knowledge. Heather did not think of scientific knowledge as merely one type of knowledge. She viewed "facts" as unchanging, but hypotheses and theories as tentative in nature. The current study was able to uncover her beliefs, and demonstrate that she did have at least a partial understanding of the tentative nature of scientific knowledge based on the way she categorized various levels of this knowledge. She did hold a fully formed understanding of scientific knowledge as being developmental in nature, even if her beliefs regarding various levels of knowledge and their "tentativeness" were not complete.

The authors of AAAS (1989) note "change in knowledge is inevitable" (p. 26) when discussing that scientific ideas are subject to revision. However, they also note scientific knowledge is durable in the sense that scientists do not outright reject established beliefs in favor of newer ones, but change occurs through a slow process of observation and of gathering new evidence. Similar to AAAS, Botton and Brown (1998) note that scientific knowledge draws its tentative and revisionary nature, in part, from the methods for developing that knowledge. Many participants in this study
echoed these positions when they described scientific knowledge as more than tentative or merely changing over time, but also as developmental and requiring "proof." This understanding of how science knowledge changes further illustrates the extent of participants' fully formed beliefs about the tentative nature of the knowledge itself.

The Scientific Enterprise: Everything is Science

In a recent qualitative study which examined student conceptions of the nature of science, Griffiths and Barman (1995) interviewed 96 high school students from Australia, Canada, and the United States. Although their results show some variation between countries, they concluded that students had conflicting or vague views regarding the nature of science. In response to the question "Is science different?" they report that an overwhelming majority of the students were quite positive that science is "different" from other areas. However, results from the current study are not always consistent with this finding, and demonstrate that students often believe that "everything is science."

Most participants in this study had difficulty distinguishing between science and non-science. In an extreme case at Valley, Lisa stated that people think of science all of the time, "whether we are conscious of it or not, just wondering why things are, how things are..." Later in the year she commented that science is done "everywhere, whether you notice it or not." Throughout the course of the study she consistently held this notion that individuals "unconsciously" think about or participate in science in
their everyday lives.

At Woodland, Ben explained that ordering lunch was science, and stated, "...in order to get lunch what you do is you have to pay first and then you bring the ticket up to the counter..." He believed there was an organized system to ordering lunch, and that because there was a method or system, ordering lunch could be considered scientific. Many participants confused the ordered, systematic elements of the process of science as being the only characteristic required to label something scientific. Participants in this study described the processes of building a house, baking cookies, and fixing a car as science because they viewed these processes as having structure and order to them.

The phases or steps of the scientific method taken together are an organized process, and the participants' beliefs were not entirely unfounded. Science is a systematic ordered process, but a process which leads toward the development of new scientific knowledge, not the acquisition of lunch. It seems that in many cases participants did not consider the context of a process as, in part, defining whether it is indeed science.

Additionally, participants' beliefs that "everything is science" highlights their lack of understanding of science as one way of knowing. Such as there are many ordered processes besides science, there are other ways in which humans may explore the universe than through science. Larry was the only participant who understood science as a way of knowing which is different from other forms of inquiry or exploration. During the second interview when discussing some differences between
science and non-science, Larry stated "(science) sort of is without looking at a [pause] a theological, spiritual...it just has to do with how things work together, material things." Because of his devout religious beliefs, he experienced and understood another way of exploring the universe besides science. Only this participant saw science as significantly "different" from other ways of knowing. It is because of Larry's understanding of a mode of inquiry which is non-scientific that he was better able to distinguish between science and other ways of knowing.

**Project-based Models and the Nature of Science**

As noted in Chapter I, following the pilot study it appeared that project-based models of instruction at both Woodland and Valley contributed to classroom settings in which students could readily learn about the nature of science. It was believed that certain elements of each class could influence students' understandings of various aspects of the model. For example, Project Seafarer emphasized questioning and communication, while the Conservation Biology class focused on authentic scientific research, especially data collection. However, very little change was seen in participants' beliefs in these or any areas across the model throughout the study. Considering that many students began the year with fully formed conceptions of many aspects of the premises, as noted in the descriptive accounts of the previous chapters, the apparent lack of change in participants' beliefs seems less disturbing. Nevertheless, we are still left with the question of whether project-based instruction is indeed an effective model by which to teach students about the nature of science.
This study illustrates that by merely involving students in science-related projects, such as those described throughout this work, they will not necessarily develop an improved understanding of the nature of science. This is the case even considering that many aspects of the project-based classes followed preferred models of teaching science as outlined by both AAAS (1989) and NRC (1996). The classes observed for this study were generally hands-on, and encouraged students to be active participants in their own learning. Additionally, they afforded students the time to explore various aspects of science, which AAAS notes is fundamental to all learning in science. There were, however, specific instances in which elements of the project-based models did have positive influences on student beliefs. As noted earlier, when communication was emphasized through Project Seafarer, Bryan came to understand the importance of this concept within a scientific context. This ultimately contributed to a more complete understanding of the nature of science for this student.

Other changes in student beliefs at Woodland may be linked to their experiences in Project Seafarer as well. Linda changed her understandings of "data" as consisting only of numbers to an understanding that data could also be comprised of non-numerical information. This change occurred as a result of her first project in which she interviewed her classmates about the project-based class. She viewed their written responses as data from which she drew conclusions. She stated following the completion of her first project, "I sent out surveys and had to take all of the information in after I got them back. So I did collect data for that one..." Additionally, Larry's understanding of the relevancy and importance of the scientific enterprise as it
relates to society evolved because of his work with the tornado project. He came to understand how societal needs, such as being able to predict tornadoes, can influence the process of science.

At Valley, authentic scientific research was emphasized in the Conservation Biology class through participation in Student-Scientist Partnerships (SSPs). At this site most participants' conceptions of the second premise of the model, which served to define the scientific enterprise, evolved over the course of the study. Specifically, most participants' understandings of how science is able to explain phenomena changed throughout the year (see Table 3). For example, several students developed the belief that science can explain certain phenomena through an understanding of relationships between various factors. That is, students developed a notion of cause and effect. This change in participants' understandings may be linked to their research efforts in class in which they searched for explanations for changes seen to local rivers and forests. For example, if pine needles were seen as abnormally yellow students considered various factors, such as air pollution, as causal agents. They began to explore the relationship between forest health and air quality.

Other changes were seen in student conceptions which may be linked to their experiences in the project-based class. For most of the year Roy believed that scientific questions are fully answerable. However, during the Forest Watch project Daria emphasized the difficulty in definitively determining causes for any decline seen in forest health. Following that point in the year he described questions in science as sometimes being complex and not fully answerable. Heather and Lisa both changed
their beliefs about the role questions play in the scientific enterprise following the salmon restoration project at Valley. In this project they had the opportunity to pursue questions of their choice. Heather investigated whether or not atlantic salmon should be placed on the endangered species list, and Lisa examined the differences between landlocked and atlantic salmon. Following this project, both students added the element of questioning to their explanations when defining science for the second premise.

Additionally, Lisa's beliefs evolved regarding the final premise of the model which states that scientific knowledge is tentative and developmental. At the beginning of the year she expressed the belief that scientific knowledge is essentially static and could not envision a means by which it could evolve. After her experiences with technology, including the use of computers for satellite image processing in Forest Watch, she understood that technology could aid in the generation of new knowledge. Ultimately she noted that knowledge could indeed evolve because she could now see a clear means by which it could do so.

These examples, from both Woodland and Valley, highlight the potential of project-based instruction to affect students' beliefs of the nature of science. Project-based models and the role questions play in their implementation is addressed in the following section.

**Questions and Questioning**

Questioning is essential to science. Callery and Koritz (1993) in an effort to
dispel common myths associated with science state, "It is commonly thought that science finds answers...science, more importantly, finds questions" (p. 154). The authors of AAAS (1989) also support the use of questions and questioning when teaching science. They write, "Sound teaching usually begins with questions...and then (students) try to find answers to their questions" (p. 147). Therefore, learning to formulate and pursue questions, especially in science-related projects, become important elements of the overall experiences students should receive in project-based instruction.

At Valley, all participants discussed the role essential questions played in the Conservation Biology class as well as throughout the school. Most participants felt essential questions were very over utilized throughout their course work at Valley. Tom noted late in the year, "That's the only thing I didn't like about Valley, it has too many damn essential questions...you have to answer it or you don't pass..." Participants felt that essential questions forced them to focus on certain predetermined areas for study. Of course, in many cases providing a focus for a class or project was a main purpose of the essential question, however participants stated that they found them overly restrictive for their course work.

Participants in the Conservation Biology class at Valley had great difficulty in even listing the essential questions which supposedly guided each class project when I inquired about them. They knew these questions existed, but could not state them, although they were aware of the general themes that these questions embodied. For example, they knew the watershed project dealt with river health and the Forest Watch...
project dealt with forest health. In most cases they felt they could have gone through the class without any essential questions at all. As Roy noted, Daria the teacher, not the pursuit of questions, guided the class activities each day.

In contrast, for his senior project Tom noted that he valued essential questions because they provided a focus. As noted earlier in this study, students at Valley are responsible for completing a senior project as part of the requirements for graduation. The senior project is a year-long, intensive effort which requires that students choose a topic, generate an essential question, conduct original research, and toward the end of the year while presenting their final project to a panel of teachers, justify the importance of their work. The senior project did not force students to use teacher-generated questions. Tom felt that his essential questions guided all aspects of his work, and that he could not have completed his project without them.

Katz (1994) explains that an essential component to projects are questions, and if this Conservation Biology class rarely made use of them, one must question if the class was indeed "project-based" in nature. In fact, I have come to think of the Conservation Biology class as not necessarily project-based, but activity-based in nature. Even with the awareness of a theme such as river health, the "project-based" work in Conservation Biology seemed to lack coherence over the course of each "project" for participants. When Daria was demonstrating some of the techniques for collecting data on the river, she said, "You will discover the why you are making these measurements after you get some numbers." Later in that same project, when I asked students why they were identifying macroinvertebrates collected from the river,
many responded, "I have no idea." When Daria did mention the overall objective of each project, she rarely phrased it as a question. This is perhaps why participants knew the theme of each project, but not the essential question. Because of this lack of emphasis placed on essential questions, students often viewed their class work as a series of disconnected "activities."

The project-based curriculum design of Project Seafarer at Woodland was more student-centered (Dwyer, 1994) than the design at Valley, especially considering the use of questions in this instructional model. Students were required to generate their own questions, tied to the Seafarer theme and their content area, and pursue them through individual projects of their choosing. Unlike participants at Valley, participants at Woodland were mostly able to recite and discuss their questions when I inquired about them. Many students, such as Linda, found them useful when working on their projects. She discussed how she utilized her essential questions when initiating the research for her projects, as well as how they helped frame all aspects of her work.

This extensive use of questions was not surprising considering that each individual project in Project Seafarer was like a very scaled down version of the senior project at Valley. The design of both projects encouraged students to develop and pursue their own questions, and both culminated in a formal presentation. When this student-centered, project-based model was utilized, students generally understood and appreciated the role of questions in their projects.

One notable exception at Woodland was Donna who did not generate her questions until the very end of each project, and only did so in order to meet the
Seafarer assessment requirement of posing and answering an essential question. Instead of basing her projects on questions, she based her work on topics or themes, such as AIDS and evolution. This ties in closely with participants' notions of research at Woodland. They viewed research as gathering or compiling information from various sources, such as the internet. As a result, Donna didn't need questions per se to conduct "research," only a topic to begin a search of WWW sites to uncover this information. In addition, she viewed questions as limiting, and stated several times over the course of the year that they would greatly inhibit her exploration of the topics she chose. By just sticking with the general topic itself, she felt she had more flexibility to investigate aspects which were of interest to her. In the end, Donna retro-fitted her questions to the information instead of using the questions to filter the exploration of her topics.

Additionally, although Larry made use of questions when pursuing his projects, he found the whole notion of essential questions somewhat confusing. He believed that essential questions should have a "philosophical entity" to them, explaining that they should not be "yes or no" questions. He believed there should be a built in vagueness to essential questions which make them somewhat challenging to answer. Larry viewed essential questions in Project Seafarer as both guiding and researchable questions as discussed in Moss et al. in press.

Clearly, the manner in which questions were utilized in the various project-based approaches at Woodland and Valley had an effect on students' beliefs about them. If students are to value the importance of questions as part of a project-based
model of instruction, they must be emphasized as in the Seafarer model at Woodland and the senior project requirement at Valley. In both of these cases, questions were generally an important aspect of the project for students, they held ownership over them, and they guided their work.

It is important to note, however, this study finds that addressing and emphasizing questions in general terms during projects for students is not sufficient for developing an understanding of their importance to the process of science. Regardless of whether participants appreciated the role of questions in their projects, most participants' beliefs about questions, as they specifically related to the scientific method, were generally lacking at both sites. Additionally, virtually no participants echoed the belief of Callery and Koritz (1993) who noted science finds questions, not answers. Only one participant discussed how the process of science typically generates new questions as a result of conducting research (see Tables 2 & 3). However, during this study the teaching of the relationship between questions and the nature of science was not necessarily a goal for either project-based class. Implications for teaching the nature of science through project-based instruction are discussed in the next section.

**Implications for Teaching**

Perhaps the most important justification for considering implications for science teaching, including the design and implementation of project-based curriculum, is that the experiences students receive in K - 12 schooling may be their only opportunity to receive formal instruction in the sciences. In their annual summary, The National
Center for Educational Statistics (1995) report that approximately one third of American high school students will attend college. In this study, Dorothy and Lisa at Valley, and Bryan and Linda at Woodland all indicated that if given the choice, they would never take another science course again. Although Project 2061 (AAAS, 1989; 1993) supports the notion that the attainment of scientific literacy is a life-long endeavor, these students' secondary school experiences may be their only formal exposure to the concepts and processes of science that will help set the stage for their journey in becoming scientifically literate citizens. Therefore, their experiences in high school become even more critical.

Making the Nature of Science Explicit

In his recent book, Doing Science, Glasgow (1996) concludes a "problem-based investigative curriculum" (p. xxiii) can support learning experiences which would be more relevant to today's educational demands. Echoing the AAAS reform recommendation, he believes such a curriculum is a critical step in achieving a scientifically literate society. He defines problem-based learning in the classroom as, "...students (taking) on problems or projects related to science subjects as a stimulus for learning in the content areas, subjects, or disciplines" (p. 12). He explains that this approach has two principal educational objectives, the acquisition of an integrated body of science knowledge and the development or application of problem-solving or reasoning skills. Hiebert et al. (1996) also support making curriculum more "problematic" as a means of improving student learning. They write:
Allowing the subject to be problematic means allowing students to wonder why things are, to inquire, to search for solutions, and to resolve incongruities. It means that both curriculum and instruction should begin with problems, dilemmas, and questions for students. (p. 12)

Both of these explanations of problem-based learning are consistent with the definition of the project-based approach to learning defined by Katz (1994). She describes a project as an in-depth investigation of a topic worth learning more about, and states key features of projects are finding answers to questions.

Nevertheless, as noted earlier, a project-based approach to science education does not ensure that students will experience and develop understandings of all aspects of authentic science, such as finding answers to questions, leading to a more complete understanding of the nature of science. Glasgow (1996) agrees, noting that an active, student-centered approach to learning, which is the underlying philosophy of many project-based curricula, does not necessarily ensure that students will experience authentic scientific inquiry. He writes, "The term hands-on or minds-on [sic] and related jargon do not guarantee that students have experienced science as a dynamic process of scientific inquiry... " (p. x). Findings from the current study are consistent with this view.

How then do we ensure students both experience and understand all aspects of the "dynamic process of scientific inquiry," an essential component of the nature of science? A simple strategy might be to make the nature of science explicit throughout all aspects of project-based instruction.

In support of the development of an understanding of the nature of science for precollege students, the developers of *Benchmarks* (AAAS, 1993) advocate that "The
study of science as a way of knowing needs to be made explicit in the curriculum" (p. 3). However, the tendency to think that the nature of science can be taught implicitly was evident at both sites because of the ways in which the nature of science was only implicitly embedded within each school’s curriculum. Although MacDonald (1996) states that conveying explicit messages about the nature of science has long been recognized as a goal of science teaching, many teachers assume it "happens automatically" (p. 183) throughout their daily instruction. Abd-El-Khalick et al. (1997) also state, "Extensive efforts should be made to help teachers avoid the apparent tendency to think that the nature of science can be taught implicitly through student participation in science activities" (p. 28).

The Project Seafarer "Grading Guide" and "Standards for World Class Learners" along with the Valley "Curriculum Framework" show the development of an understanding of the nature of science was an implicit curricular goal (see Appendices B, C, and D). Although the Valley framework specifically discusses the overarching notion of scientific literacy, which demands the nature of science must be addressed at some point, the Seafarer standards and grading guide only address the nature of science, such as questioning, less directly. Therefore, perhaps the first step in making the nature of science more explicit in project-based curriculum, or any curriculum in which it is a goal, is to ensure that it is explicit in the curriculum goals and materials themselves.

Of course, merely making changes to curricular guidelines is insufficient. As MacDonald (1996) noted it is especially critical to make the nature of science apparent
throughout the course of instruction. In this study there were instances in which participants were not aware that their classroom experiences were indicative of various aspects of the nature of science, and it was not made explicit to them. For example, Dorothy noted she made use of the "steps" which characterize the scientific method throughout the course of the year, but was not entirely sure. She stated,"I think we've been following them" regarding these steps and her experiences in Conservation Biology. She also noted, like several participants, that she hadn't gone over the steps in science class since her freshman or sophomore year. Although she did note that the steps were an ordered process, and even commented that a hypothesis might be "what you think might happen," she was unable to describe the purpose for or the relationship between most of the individual steps. She confused them with the setup of a lab report which is why she often mentioned "procedure" when describing the scientific method. Her conceptions of the premise which dealt with the scientific method were only partially formed and unchanging over the course of this study. In this case, if it were made explicit to Dorothy how she was in fact making use of the "steps," and was directly experiencing an important aspect of the nature of science, her beliefs regarding this premise may have evolved toward a more fully formed conception over the course of the year.

How can we make the nature of science more explicit throughout project-based instruction? As discussed in Chapter IV, perhaps by using an instructional model like one advocated by Trowbridge and Mintzes (1985) in which examples and non-examples of concepts are used, teachers can explicitly address many of the ideas
surrounding the nature of science.

The use of examples and non-examples is, in part, based on the concept attainment model of conceptual learning (Bruner, Goodnow, and Austin, 1967). Bruner and colleagues describe that at the heart of their model is "the search for and listing of attributes that can be used to distinguish exemplars from nonexemplars" (p. 233). An activity which is modeled after the concept attainment work and designed to foster an understanding of science would begin by listing the characteristics of science and non-science, and encourage students to search for patterns which characterize the two concepts. By learning what is not science, the concept of science would be better understood.

Some of these characteristics or attributes of science would be essential attributes, which are "those that are critical to the domain under consideration" (Joyce & Weil, 1992, p. 148). In addition to ordered and systematic, content specific words to science would be included as essential scientific attributes so that students would come to understand that content also defines science. A non-essential attribute of science might be "technology." Although many individuals associate technology with science, and science certainly makes extensive use of it, one can do science without it. Ultimately, students would learn a wide range of attributes relating to science by exploring the various essential and non-essential characteristics of it. An exercise such as outlined here would be a first step in making the nature of science explicit in classroom activities.
Questioning

As noted earlier, participants at Valley were rarely able to recite the essential questions which supposedly guided their project work. As a result, most students did not view questions as essential to the process of science, and viewed Daria, the teacher, as solely directing the science work in class. If there was a greater emphasis placed on essential questions in class, perhaps participants would have seen the questions themselves, and not Daria, as guiding this class. Of course, I do not propose that teachers like Daria have a reduced role in classroom instruction, just a different one.

As Glasgow (1996) writes, these projects should proceed "in collaboration with, and with the facilitation of, the teacher" (p. 4). If Daria facilitated the consistent use of questions throughout the year, perhaps students would have viewed questions positively in class, and would come to rely on them as several students did while working on their senior projects. A simple strategy might be to revisit the questions guiding each project on a regular basis and make it clear how the work students are engaged in on a particular day will contribute to answering the question at hand.

If students had more opportunities to not only make use of essential questions that were provided for them, but to develop their own questions over the course of each project, like they did in the salmon restoration project, they might not find them so restricting as they did in many of their classes. When this was done, several students began to include the notion of questions and questioning in their definition of science. These changes could facilitate an improved understanding of the importance
of questions and questioning in science at Valley, perhaps leading to an overall improved understanding of the nature of science for students.

At Woodland, although this study found students generally had a more positive view regarding the role of questions in their projects, they still had difficulties with them. For example, Larry's science question, "Is the ocean a good enough barrier to prevent the spread of a lethal disease?" highlights a potential problem with how essential questions were utilized in Project Seafarer. As noted earlier, in one sense they were guiding questions, merely setting the stage for Larry's thinking and work, however they also served as his researchable questions which should be used to directly guide the research process. This is where the fundamental problem was and the basis for Larry's confusion existed. Larry successfully posed only guiding questions, however utilized them as researchable ones.

Larry's question about the spread of lethal diseases is an interesting and important question, however it should have only served to orient the direction of his project. Perhaps after he had considered this area for investigation for a short time, and collected some resources, he could have followed up with a more focused researchable question which would have guided the remainder and bulk of his project-based work. If one were to follow up on the lethal disease guiding question, certainly one would pose a question which examined a particular disease, not all diseases in general. His project would have had considerably more focus than just describing diseases in general (see Appendix E), and perhaps would have removed some of the "vagueness" that he perceived in these questions and projects.
When teachers facilitate a student-centered, project-based model which relies heavily on the generation of questions, they should work closely with their students and ensure they consider both the notions of guiding and researchable questions. Perhaps projects can have two distinct phases. The first might be similar to the way projects are currently done in Seafarer and the second phase might involve researchable questions and the collection of original data. For example, after Larry completed the first phase of a project in which he examined a certain disease, including its mode of transmission, typical range, etc., through the acquisition of material from various sources, he could then follow up with a relating project in which he collected original data. For instance, he could count bacteria left on an open petri dish or some other doable study in which the concepts uncovered from the first aspect of the project were enforced. Such a multi-phase project would not only continue to encourage students to appreciate the role of questions in projects, but may also help to foster a broader understanding of research and the nature of science.

Time

As lead teacher, Jack spent a great deal of time managing the technological resources for Project Seafarer along with numerous other responsibilities at Woodland. At Valley, Daria also had many responsibilities besides classroom instruction and as a result, also experienced difficulties with time management. Even so, the goals of these energetic teachers for each class, such as the number of projects at Woodland and the amount of data collected at Valley, were extremely high.
On any given day, Jack was overseeing the computer system in class, helping individual students with their projects, coordinating mentor teacher and UNH intern responsibilities, managing issues regarding the construction of the boat, such as the wood available for planking, and often sitting on a panel assessing student presentations. He kept a "to do" list up on the front board which never diminished over the course of the year. Although the student to faculty ratio in Seafarer was nearly equal, Jack was primarily responsible for keeping the class running smoothly. Even given two full periods a day, Jack found it difficult to meet the goals he developed for the class.

In an effort to ensure that the boat was completed at the end of the year, Jack made the decision about halfway through the year to re-work the class schedule to ensure that every student spent equal time on building the boat and working on their individual academic projects. The restructuring of the weekly class schedule allowed for larger blocks of time to be spent on academic work or boat building, resulting in students making more efficient use of their time. Double-block periods were rarely split between the two areas of class after restructuring. With larger blocks of time allocated toward each area, students did not have to re-focus their efforts as often, being able to make more progress on their work. This strategy was effective, and the boat was launched at the end of the year.

Toward the end of the year when Daria was reflecting upon her feeling that there was never enough time to work on the projects in Conservation Biology, she exclaimed, "Just let me teach!" She cited committee work which was mandatory for all
Valley teachers, snow storms, holiday breaks, the lack of double-block periods, and senior projects as all placing time constraints on the class and affecting the flow of the project work throughout the year.

Perhaps longer, uninterrupted blocks of time in which students could pursue their project work, such as at Woodland, may have alleviated some of the time pressures Daria felt. In a recent article, Bohince (1996) addresses various issues regarding block scheduling of science classes. She notes it is sometimes difficult to motivate students for these longer periods. Regardless, I believe a project-based class such as Conservation Biology would greatly benefit from longer blocks of time, improving the continuity from class to class while fostering a greater sense of the "project" for students, like at Woodland. Students would be able to use their time more effectively by not having to re-focus their efforts each class.

Kuhn (1997) states that we should engage students in simplified, but authentic activities modeled on real science. If we are to do this, then restructuring available time is essential. I know of no "authentic" science team restricted by 50 minute blocks of time in which to conduct their work. Therefore, larger blocks of time than the traditional 50 minutes are necessary if students are to truly experience authentic science projects in schools. At Valley, Tom thought of "school science" as fundamentally different from "real science," even though the class was participating in SSPs such as the Forest Watch program with UNH. Perhaps longer blocks of uninterrupted time will help minimize the "school science" in authentic school-based science projects.
Revisiting the Model

As discussed in Chapter II, at a recent NARST conference, science educators reached a consensus that the phrase natures of science better provided for a range of acceptable but often diverse definitions of science than the commonly used expression "nature of science." Although I strongly support the notion that there should exist a range of satisfactory meanings to describe this complex human endeavor, a standardized definition of fully formed understandings of the nature of science was noted to have been lacking from many research studies (Lederman, 1986). This was the principal reason for developing the model utilized throughout this study, to assess high school students' understandings about the nature of science. It is fitting to think of this model as merely one suitable model of the natures of science, precisely, a model geared toward K - 12 education.

The following model was generated, and utilized throughout the course of this study:

The premises which characterize the scientific enterprise are:

1.) The universe is open to human description, classification, and understanding through scientific exploration.

2.) This scientific exploration attempts to explain and predict phenomena, compare theories, check on previous results, and generate new questions.

3.) Logic, imagination, curiosity, and serendipity contribute to scientific exploration.
4.) Scientific activity is a social activity conducted by individuals who are influenced by both cultural and personal factors.

5.) Questioning, data collection and analysis, drawing of conclusions, and communication are the major phases which characterize the scientific endeavor.

The premises which characterize scientific knowledge are:

1.) Scientific knowledge demands evidence, and is testable through the scientific enterprise.

2.) Scientific knowledge cannot provide complete answers to all questions.

3.) Scientific knowledge is tentative, developmental, and subject to revision.

As one considers the various principles of this model, inconsistencies in its underlying philosophy may be discerned. This model is post-positivistic, emphasizing the human role in the process of generating and reporting scientific knowledge. In a recent article, Loving (1997) traces the early history of positivism, citing the influences of Plato, Galileo, and Copernicus as contributing to the notion that only "empirically verifiable" (p. 428) statements are those which may be considered scientific. The fifth premise of the model which outlines the phases of the scientific method, along with the tenet which states that scientific knowledge demands evidence both support a positivist perspective. However, what of the premise which describes science as a social activity, susceptible to such human influences as cultural and personal factors? Is this not contradictory to the positivist underpinning of these other premises?
Garrison and Bentley (1990) describe postpositivism as asserting that universal laws can never be induced with certainty. They note there is an element of subjectivity to all statements. Loving (1997) describes postmodern science as also dismissing positivist tenets when she states:

...it concentrates on how the natural sciences are actually carried out (rather than how they should be carried out) in the context of social, political, or psychological dimensions. [sic] (pp. 432-433)

In that sense, perhaps postmodernism, or postmodern science, better captures the essence of science as a social activity than merely a post-positivistic perspective. I believe postmodernism still allows for rational thought to prevail in science, while also recognizing the "highly interpretive and variable" (Loving, 1997, p. 433) elements of science. When we consider that the scientific endeavor is very much a human endeavor, we can more easily accept science as both rational and subjective. However, Loving cautions against reducing the nature of science and the knowledge it reveals to simply opposing views.

When using a model of the nature of science as a measure to determine if student conceptions are fully formed, we must consider such a model as merely a benchmark by which to begin to assess student understandings. Ideally, after reflection upon their own understandings of science, students would develop thoughtful philosophical positions upon which to develop their own model of the nature of science. If we are to truly support diverse natures of science, then like the model presented in this study, perhaps it should not be unexpected to see models generated with apparent philosophical contradictions. By embracing those inconsistencies we
make it explicit to students that in this modern age there is still disagreement regarding the "true" nature of science. Accepting such models does not force the developers into one extreme philosophical position, but encourages them to weigh the merits of each, and perhaps find their place on the continuum between the many views. More importantly, by encouraging students to critically examine their beliefs, we invite them into this interesting and important dialogue.

Regarding the model developed for use in this study and its philosophical stance, I pose the question: Is it difficult to imagine a nature of science as requiring evidence to justify its claims, and at the same time recognizing the limitations of human beings in the pursuit of that evidence? For me it is not, and thus I have found my place on the continuum.

Revising the Model

Having completed this study, I believe some minor changes to the model are necessary for the purpose of clarification. The first change to the model would be regarding the initial premise which states that the universe is open to human understanding through scientific exploration. Although I would keep the original essence of this premise, I would also make it explicit that science is merely one way of knowing. Lee (1997) believes that in order to even conceptualize the notion of scientific literacy, educators first need to be clear about what counts as science. A clear recognition that there are scientific and non-scientific ways of knowing may be the first step in deciding what counts as science.
The next alteration to the model is in the fourth premise of the model which describes science as a social activity. The revised premise would state, "Science is a social activity, both influencing and responding to social needs. Scientists themselves are influenced by cultural and personal factors, such as cultural norms and their own lived experiences." Lewontin (1991) perhaps stated it best when he noted that we should be acquainted with science as a social activity to ensure that we have reasonable skepticism about the sometimes sweeping claims that modern science makes. This premise is not designed to be anti-scientific, but to ensure that we are critical consumers of science, which entails a realistic understanding of its limitations.

Another important change would be to the fifth premise, "Questioning, data collection and analysis, drawing of conclusions, and communication are the major phases which characterize the scientific endeavor," addressing the scientific method. In addition to the premise as it already stands, I would make it explicit that both experimentation and naturalistic observation are important to the process of science. This allows for research designs which both manipulate variables and make use of controls, and for those which aim to describe natural phenomena. A change such as this emphasizes a more complete, accurate portrayal of the way science is actually done.

Finally, I would make changes to two premises of the model which deal with the nature of scientific knowledge. Instead of stating that scientific questions cannot be fully answered, I would note that they usually cannot be answered. This simple change accounts for a wider range of scientific questions. I would also remove the last phrase...
of the final premise which states that scientific knowledge is subject to revision, since this is already captured when it is stated that knowledge is tentative. This revised model of the nature of science appears as follows:

The premises which characterize the nature of the scientific enterprise are:

1.) The universe is open to human description, classification, and understanding through scientific exploration, however science is merely one way of coming to know our universe.

2.) This scientific exploration attempts to explain and predict phenomena, compare theories, check on previous results, and generate new questions.

3.) Logic, imagination, curiosity, and serendipity contribute to scientific exploration.

4.) Science is a social activity, both influencing and responding to social needs. Scientists themselves are influenced by cultural and personal factors, such as cultural norms and their own lived experiences.

5.) Questioning, data collection and analysis, drawing of conclusions, and communication are the major phases which characterize the scientific endeavor. Research designs which make use of both experimentation and naturalistic observation are commonly used.

The premises which characterize the nature of scientific knowledge are:

1.) Scientific knowledge demands evidence, and is testable through the scientific enterprise.
2.) Scientific knowledge usually cannot provide complete answers to all questions.

3.) Scientific knowledge is tentative and developmental.

Summary of Findings

1.) The current study demonstrates that qualitative methodologies, especially formal interviewing in combination with participant observation, are effective at uncovering and identifying students' conceptions of the nature of science which they bring to and develop in learning environments. Therefore, qualitative studies can significantly add to our knowledge base of students' beliefs of the nature of science.

2.) By the end of the year participants at both classroom sites held fully formed conceptions of the nature of science for approximately 40 percent of the premises across the model. Generally, students held more complete understandings of the nature of scientific knowledge than the nature of the scientific enterprise.

3.) Regardless of whether or not participants' overall conceptions of a premise were fully formed, for nearly two-thirds of the elements which comprise the premises participants held full understandings. These findings indicate that students' beliefs may not be as poor as outlined in previous studies which conclude that students exhibit inadequate understandings of the nature of science.
4.) Overall, participants' conceptions of the nature of science remained unchanged over the year for approximately three-quarters of the premises. Students at both classroom sites generally began the year with either partial or full understandings of many premises, and their beliefs remained consistent throughout the study.

5.) This study illustrates that by merely involving students in science-related projects, they will not necessarily develop an improved understanding of the nature of science. There were, however, specific instances in which elements of the project-based models did foster a change in student beliefs.

6.) Most participants in this study had difficulty distinguishing between science and non-science, confusing the ordered, systematic elements of the process of science as being the sole characteristic which defines science. Additionally, participants held poor understandings of the role questions play in the scientific enterprise.

7.) Implications for successfully teaching the nature of science through project-based instruction include making the nature of science explicit through all aspects of curriculum, teaching the nature of science through the use of examples and non-examples, emphasizing guiding and researchable student-driven questions, and restructuring class time to allow for uninterrupted blocks in which students can pursue research.
Implications for Further Research

Methodology

There are several important implications for future work to emerge as a result of this study. The first centers around the nature of qualitative research. The main objective of the current study was to describe student conceptions of the nature of science. However, because this study finds that precollege student beliefs may not be as poor as described extensively throughout the science education literature over the past several decades (Lederman, 1992), additional studies should be undertaken to help explain these apparent differences.

I propose that future studies focus on participants across grade levels, and develop models of the nature of science appropriate for all students K-16. They should employ a research design with frequent interviews and observations similar to the design of this study. Studies such as these will provide rich narratives further describing the limits and boundaries of student understandings of the nature of science, a much needed knowledge base for science educators (Lederman et al., 1997). They also will be able to identify and track additional concrete examples of the affect science teaching has on the development of student conceptions of the nature of science. Data such as this is needed for developing further recommendations for improving the teaching of science.

Student Conceptions

Specific areas for further study arose from examining student conceptions. The
first area to be considered in greater detail is the "everything is science" phenomena described in this study. As seen in Appendix C, the "Standard for World Class Learners" in part states, "See how science relates to other disciplines and to all aspects of the world." This standard is designed to highlight the importance and relevancy of science in today’s world. It was suggested in this study that when science educators attempt to show that science is indeed relevant, perhaps students take that notion to believe that everything is science. Studies which investigate this finding, seeking to further describe and explain why students have adopted this belief, is an area for continued research.

Next, the finding that very few students described serendipity as contributing to the scientific endeavor should also be addressed through further study. The National Science Teachers Association (1996) A Framework for High School Science Education notes, "Little research has been reported on the use of history in teaching about the nature of science" (p. 181). They conclude that learning about the history of science might serve to improve students’ understandings about science. If students examine historical or present day accounts of actual scientific studies, perhaps they will better see the role of serendipity in science. Ideally they would understand science as often involving logic, imagination, creativity, and serendipity. Such an understanding might better enable students to see science as a human endeavor, where both "luck" and the prepared mind play an important role.
Teacher Conceptions

Another important area for research to be undertaken is one that is currently underway. Abd-El-Khalick and BouJaoude (1997) discuss teachers' conceptions of the nature of science. They found teachers' conceptions lacking, which is of concern because teachers understandings of science will potentially have an impact on students' beliefs. However, that relationship is poorly understood. They conclude that "Teacher preparation programs need to emphasize teachers' content knowledge" and that these programs can no longer be "content-free domains of pedagogy" (p. 693). They hope such changes will enrich teachers' content knowledge base while improving their conceptions of the nature of science. Loving (1997) also notes the way teachers are prepared should be transformed, "Science teacher education should...provide science methods and science classes that promote...explicit discussions of views of the nature of science" (p. 447). Further research into the relationship between teacher and student conceptions, as well as research into what these modified teacher education programs which emphasize the nature of science might look like, are urgently needed.

Conceptual Change

Further research should also be centered around understanding the mechanisms for conceptual change. Good (in press) notes an understanding of how students are to change their knowledge is essential for the science education community. Such an understanding will have direct implications for how we teach science into the next century.
In this study, examples of conceptual change as described by Posner et al. (1982) and Southerland (1997) were demonstrated. However, in some cases when change did occur, it was difficult to determine the exact cause or mechanism for that change. Perhaps a more ethnographic study involving greater time in the school setting and fewer participants would allow for the collection of data which addresses this important area.

In addition, experiences students receive outside the science classroom will also have to be addressed and understood. In a related area of research, Clough (1997) notes that numerous studies deal specifically with students' alternative conceptions of science. When studying alternative conceptions, researchers should also continue to look outside of the formal school setting to learn their origin.

Technology

Results from the pilot and second year study suggest that technology was an important issue in the project-based class at Woodland. Whether during the pilot year when participants often discussed the lack of available resources for conducting research and presenting their projects, or during the second year when computers were readily available, students struggled for ways to integrate the technology into the learning of their content areas.

Muir (1994), an advocate for the use of technology in schools, very nicely summarizes his educational philosophy regarding the use of technology which is remarkably similar to that of Project Seafarer. He writes, "Learning to use the
computer is only a secondary objective. The primary objective is to learn ideas from math, science, language arts, social studies, or some other content area" (p. 30). In support of the use of technology in the classroom, Hunter, Bagley, and Bagley (1993) write, "To prepare students for the information age, educators must encourage them to become familiar with today's technology" (p. 3). However, simply becoming "familiar" with technology or merely having it available for students is not enough if that technology is to be used as a tool for learning in the content areas. Future work which explores how technology can best support curriculum goals in science and other areas is greatly needed.

Building Upon Success

In this final section, I would briefly like to address the notion of building upon the many positive and exciting outcomes identified from this study. I have noticed that many educational studies seem to focus on what is wrong in schools today, and perhaps this dissertation is also guilty of that. It seems people want to know what needs to be "corrected" and assume that positive happenings will take care of themselves.

At Valley, the involvement of the Conservation Biology class in authentic research through SSPs should be continued. Glasgow (1996) notes, "There is a growing division between the way science is taught as a series of facts...and the way science is being conducted" (p. ix). These SSPs are an excellent model of how to bring "the way science is being conducted" into the classroom. There are some
modifications to this model discussed in Moss et al. (in press) and in this study, but we should not overlook the many positive experiences students are receiving as a result of participating in these partnerships.

One such positive outcome is the experience students receive with the "tools" of conducting science. Students became proficient with tools for making measurements of river and forest health, which is no minor accomplishment. They learned to independently collect and record sophisticated data on river velocity, forest canopy closure and other authentic measurements which scientists in these various fields routinely make. This work is a far cry from the cookbook approach to science labs that is described in Clough (1994). In learning to use such tools, students are learning and experiencing an important aspect of the nature of science.

At Woodland, there were many positive aspects to the Project Seafarer class. This student-centered approach to learning encouraged students to generate questions which they pursued through their own individual work. Students took responsibility for their own learning and took pride in their work and themselves. Jack hopes that Project Seafarer will someday become obsolete. He doesn't envision that every class at Woodland will build a boat, but hopes that elements of this project-based model will be adopted by teachers throughout Woodland. Future work should help teachers at Woodland understand and adopt many of these positive elements routinely seen in this class.

Finally, I wanted to reiterate that students held many fully formed understandings of various elements of the premises of the nature of science at both of
these schools. Woodland and Valley are generally succeeding in the overarching goal of fostering scientifically literate citizens. I hope this research can help them and others to continue to succeed.
APPENDIX A

PARTICIPANT CONSENT FORM
Consent Form

Introduction: Acquiring knowledge about a particular subject such as science or social studies does not necessarily lead to an understanding of how experts in that subject area developed that knowledge. For example, you don't learn to drive a car by listening to a person tell you how to drive a car. You start by driving the car with an experienced driver who coaches you. Eventually, with enough practice you can drive the car solo. The same idea transfers to the classroom. The purpose of this project is to determine how students learn through project oriented classes. I will be looking at student work for what and how they learned throughout the course of the year. To provide additional insights, students will be interviewed for approximately 30 minutes for six times over the 1996-97 school year. These interviews will be audio-taped and transcribed. All transcripts will be available to students and parents upon request. The identity of the participants will not appear on their work, audiotapes, transcripts, or any written reports. Data gathered from this research will be used to improve the project oriented class for both the students and teacher. If you have ANY questions, please do not hesitate to contact me, David Moss, at The University of New Hampshire 862-2210.

1. I understand that my consent to participate in this project is completely voluntary and that I may discontinue my participation at any time.

2. I understand the scope, aims, and purpose of this study, the procedures to be followed, and the expected duration of my participation.

3. I understand the use of human subjects has been approved by the University of New Hampshire Institutional Review Board for the Protection of Human Subjects in Research.

4. I understand that the confidentiality of all data and records associated with participation in this research, including my identity, will be fully maintained.

5. I understand that I will not be provided financial incentive for my participation by the University of New Hampshire.

6. I understand I will receive no rewards (including grading incentives) or penalties for participating in the research project.

7. I understand that I will have an opportunity to read a summary of the study's findings at the conclusion of my involvement in this project if I so desire.

8. I understand that if I have questions about my rights as a participant in this study I may discuss those issues with a member of the Institution Review Board (862-2003).

I certify that I have read and fully understand the purpose of this project.

I, __________________________, Consent/Agree to participate in this project. (print student name)

Signature: __________________________ Date: __________________________

I, __________________________, Consent/Agree to allow my child to participate in this project. (print parent/guardian name)

Signature: __________________________ Date: __________________________

Please write your phone number and best time to reach you if you would like me to contact you with more information about the project.
APPENDIX B

WOODLAND HIGH SCHOOL

PROJECT SEAFARER GRADING GUIDE
<table>
<thead>
<tr>
<th>Topic</th>
<th>Quality includes the following:</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear Statement Of Essential Question And Purpose Of Presentation.</td>
<td>• Evidence of much thought before deciding on question.</td>
<td>Quality</td>
</tr>
<tr>
<td></td>
<td>• Question is an essential question.</td>
<td>Above average</td>
</tr>
<tr>
<td></td>
<td>• Question reinforced throughout presentation.</td>
<td>Average</td>
</tr>
<tr>
<td></td>
<td>• Question revisited at end.</td>
<td>No credit</td>
</tr>
<tr>
<td>Clear Answer Given to Essential Question</td>
<td>• Answer is fact based</td>
<td>Quality</td>
</tr>
<tr>
<td></td>
<td>• Communications were clear and understandable.</td>
<td>Above average</td>
</tr>
<tr>
<td></td>
<td>• Evidence of good understanding of facts.</td>
<td>Average</td>
</tr>
<tr>
<td></td>
<td>• Answers given from different viewpoints.</td>
<td>No credit</td>
</tr>
<tr>
<td></td>
<td>• Answer reinforced at end of project.</td>
<td></td>
</tr>
<tr>
<td>Appropriate Use Of Supporting Facts In Giving Answer</td>
<td>• Research from several sources.</td>
<td>Quality</td>
</tr>
<tr>
<td></td>
<td>• Supporting facts relate well to essential question.</td>
<td>Above average</td>
</tr>
<tr>
<td></td>
<td>• Presenter has broader knowledge than shown in presentation.</td>
<td>Average</td>
</tr>
<tr>
<td></td>
<td>• All sources are referenced in presentation.</td>
<td>No credit</td>
</tr>
<tr>
<td>Appropriate use of Technology for Presentation</td>
<td>• Presentation technology enhanced learning in audience and presenter.</td>
<td>Quality</td>
</tr>
<tr>
<td></td>
<td>• Presentation technology was the appropriate choice for this presentation</td>
<td>Above average</td>
</tr>
<tr>
<td></td>
<td>• Communicated in a variety of ways (sound, video, text, graphics, handouts, verbal presentation...)</td>
<td>Average</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No credit</td>
</tr>
<tr>
<td>Clear And Effective Teaching</td>
<td>• Information was presented in an organized fashion.</td>
<td>Quality</td>
</tr>
<tr>
<td></td>
<td>• Presentation allowed for questions.</td>
<td>Above average</td>
</tr>
<tr>
<td></td>
<td>• Presentation appropriate for intended audience.</td>
<td>Average</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No credit</td>
</tr>
<tr>
<td>Overall Quality of Presentation</td>
<td>• All content expectations have been met.</td>
<td>Quality</td>
</tr>
<tr>
<td></td>
<td>• No noticeable mistakes in presentation (spelling, accuracy).</td>
<td>Above average</td>
</tr>
<tr>
<td></td>
<td>• Presentation was artistically pleasing.</td>
<td>Average</td>
</tr>
<tr>
<td></td>
<td>• Length was adequate.</td>
<td>No credit</td>
</tr>
<tr>
<td></td>
<td>• Presentation was well balanced and maintained interest.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• It all worked!!!!!!!</td>
<td></td>
</tr>
</tbody>
</table>
### Process:

<table>
<thead>
<tr>
<th>TOPIC</th>
<th>Quality includes the following:</th>
<th>ASSESSMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appropriate use of Research Sources</td>
<td>• Use of all appropriate technological sources (CD ROM, internet, eMail, video, laser disk...)</td>
<td>• Quality</td>
</tr>
<tr>
<td></td>
<td>• Use of all appropriate non-technological sources (journals, books, interviews,...)</td>
<td>• Above average</td>
</tr>
<tr>
<td></td>
<td>• Sources properly cited in presentation.</td>
<td>• Average</td>
</tr>
<tr>
<td></td>
<td>• Credit given to artists whose work is used.</td>
<td>• No credit</td>
</tr>
<tr>
<td>Appropriate use of Deadlines</td>
<td>• Deadlines were reasonably set.</td>
<td>• Quality</td>
</tr>
<tr>
<td></td>
<td>• Deadlines were respected (met or changed with good reason).</td>
<td>• Above average</td>
</tr>
<tr>
<td></td>
<td>• Deadlines were used in a way that enhanced quality of presentation.</td>
<td>• Average</td>
</tr>
<tr>
<td></td>
<td>• Deadlines were used in a way that enhanced learning.</td>
<td>• No credit</td>
</tr>
<tr>
<td>Use of Critical Friends</td>
<td>• Use of critical friends at beginning, middle, and at end of project.</td>
<td>• Quality</td>
</tr>
<tr>
<td></td>
<td>• Completion of at least three critical friends sheets.</td>
<td>• Above average</td>
</tr>
<tr>
<td></td>
<td>• Evidence that comments were taken seriously.</td>
<td>• Average</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• No credit</td>
</tr>
<tr>
<td>Connections to Past Projects</td>
<td>• Evidence that current work is connected to learning gained in past projects.</td>
<td>• Quality</td>
</tr>
<tr>
<td></td>
<td>• Evidence of continued growth since earlier project.</td>
<td>• Above average</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Average</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• No credit</td>
</tr>
<tr>
<td>Pushed Limits of Knowledge and Abilities.</td>
<td>• Significant subject area knowledge gained.</td>
<td>• Quality</td>
</tr>
<tr>
<td></td>
<td>• Significant computer knowledge gained.</td>
<td>• Above average</td>
</tr>
<tr>
<td></td>
<td>• Evidence of struggle to gain knowledge.</td>
<td>• Average</td>
</tr>
<tr>
<td></td>
<td>• Ability of discuss learning processes</td>
<td>• No Credit</td>
</tr>
<tr>
<td>Growth Toward Understanding Standards of World Class Learners</td>
<td>• Standard(s) of subject area world class learner evident in presentation.</td>
<td>• Quality</td>
</tr>
<tr>
<td></td>
<td>• Ability to discuss standard(s) of world class learner.</td>
<td>• Above average</td>
</tr>
<tr>
<td></td>
<td>• Thoughtful comparison of standard(s) with this project.</td>
<td>• Average</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• No credit</td>
</tr>
</tbody>
</table>

**COMMENTS:**

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APPENDIX C

WOODLAND HIGH SCHOOL

PROJECT SEAFARER STANDARDS FOR WORLD CLASS LEARNERS
MATH:
• Collect, analyze, and interpret data in order to creatively solve problems and predict outcomes.
• Perform mathematical research.
• Explain complex ideas.
• Utilize mathematics to model real-life situations.
• Utilize mathematics to predict how the world behaves.

SCIENCE:
• Use knowledge as a vehicle to do good for humankind.
• See how science relates to other disciplines and to all aspects of the world.
• Use curiosity and perseverance as tools in the quest for scientific knowledge.
• See the complex in simple terms in order to communicate ideas and knowledge to people of any ability.
• Interpret data objectively.
• Find novel and/or creative methods for solving problems.

HISTORY:
• Understand the effects of our actions on following generations.
• Understand world problems.
• Utilize historical knowledge to create something that is of value to society.
• Analyze varying viewpoints.

ART:
• Impact an audience through art.
• Utilize materials and techniques.
• Understand the limitations created by size, physics, time, availability, and material.
• Transform an idea into reality.

CRAFTSMANSHIP:
• Select the proper tool and/or machine and use it in a safe and proper manner.
• Select the proper materials and products.
• Apply knowledge of structure and function to the design process.
• Complete projects with a high degree of accuracy.
• Communicate ideas to others.

ENGLISH:
• Actively listen for purpose and demonstrate understanding.
• Speak to inform, demonstrate, or persuade by using a clear theme.
• Organize a formal presentation with details and transitions to reach and impact an audience.
• Reading
  • Read varied material.
  • Comprehend literally and interpretively.
  • Critique author's intent.
  • Analyze material for meaning and value.
  • Initiate own reading for pleasure and information.
• Writing
  • Appropriately write on assigned and self selected topics.
  • Effectively organize and sequence information in a paper.
  • Edit to eliminate errors.
  • Create an emotional impact.
APPENDIX D

VALLEY HIGH SCHOOL

SCIENCE CURRICULUM FRAMEWORK
Science Curriculum Philosophy:

The philosophical belief and foundation of Valley High School's science curriculum is that all students need to be scientifically literate and active contributors of new knowledge to our local and global communities.

As such, knowledge is defined as being derived through active student inquiry.

As such, scientifically literate is defined as a student who: “recognizes mathematics, technology, social sciences, and the natural sciences are interdependent human enterprises with strengths and limitations; understands key concepts and principles of science; is familiar with the natural world and recognizes both its diversity and unity; and uses scientific knowledge and scientific ways of thinking for individual and social purposes.” (Project 2061; AAAS)

Therefore, the science faculty are committed to:

PRINCIPLES OF LEARNING:

Students learn to do well only what they practice doing
Effective learning by students requires feedback
Expectations affect performance

PRINCIPLES OF TEACHING:

Start with Essential Questions about nature
Actively engage students
Concentrate on the collection and interpretation of evidence
Insist on clear expression
Provide a historical perspective
Use a team approach
Encourage knowing by finding out
Depth versus breadth
Welcome curiosity, creativity, questions, and discussion

(Adapted from: Project 2061; AAAS)
APPENDIX E

EXAMPLE OF STUDENT WORK FROM WOODLAND HIGH SCHOOL

LARRY'S PAPER ON DISEASES
Disease is the abnormal state or functioning of all or part of an organism. In humans, diseases are categorized as acute, or severe and short-term; chronic, or long-term; and recurrent, or periodic. Human diseases are usually classified according to the cause or causes.

Infectious diseases are caused by such external agents as bacteria, viruses, and parasitic worms, and are transmitted by humans, animals, insects, or substances. For example, malaria is transmitted by an insect and colds and viral pneumonia from person to person. Diseases caused by parasites usually have a more complex method of transmission. Pork tapeworms and sheep liver fluke require one or more intermediate host organisms to complete their life cycle. Other external agents that cause diseases include such chemical and physical agents as radiation, which causes radiation sickness and aplastic anemia; irritants, which cause such occupational diseases such as black lung.

Diseases may arise from internal causes. These include hereditary disorders, which are transmitted by the genes and chromosomes of one or both parents. Huntington’s chorea is a dominant genetic disease and is carried by one gene; thus only 1 parent need be affected by the disease in order to pass it on. Recessive genetic diseases do not show up in children unless both parents are carrying a gene for that particular disease. Sex-linked disorders are carried on the X chromosome. Genetic diseases such as Down’s syndrome are caused by defects in the chromosomes.
themselves, such as the presence of an extra chromosome or the loss of part of a chromosome. Congenital diseases arise from abnormal development of an individual throughout pregnancy or from maternal influence, for example, congenital syphilis.

Each organ system is subject to particular diseases. The circulatory system is subject to heart diseases such as valve damage from arteriosclerosis, which narrows the blood vessels. Blood diseases include leukemia. The musculoskeletal system can be weakened by many diseases, including osteogenesis imperfect, which is the presence of weak, brittle bones. Tumors, or abnormal growths, may affect any organ or organ system.

Body systems can also be affected by disease. The immune system, which forms antibodies against foreign agents such as bacteria, can, in some diseases, manufacture antibodies that attack the body itself— for example, the rheumatoid disease arthritis. Degenerative diseases occur as the result of the natural aging processes.

- **Penicillium Growing in Agar**
  Penicillin is an important antibiotic derived from the mold *Penicillium notatum*, pictured here. Penicillin is effective against a wide range of disease-causing bacteria. It acts by killing bacteria directly or inhibiting their growth.

  The psychosomatic disorders are believed to be the result of emotional stress. Examples include peptic ulcers and some forms of colitis.
Macrophage on Asbestos

Macrophages normally engulf small particles in the lung. Asbestos particles, however, tend to rupture the macrophage on contact, releasing its contents into the surrounding lung tissue. This condition is characteristic of people suffering from asbestosis, a disease caused by the inhalation of asbestos fibers.

I hope that this paper has helped you learn more about diseases.

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Matthews, M.R. (1996). What should be the goal in teaching about the nature of science? Paper presented at the annual meeting of the National Association for Research in Science Teaching, St. Louis, MO.


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