The Pennsylvania State University

The Graduate School

Department of Curriculum and Instruction

ON-LINE PEER REVIEW AND STUDENTS' UNDERSTANDING OF THE NATURE OF SCIENCE

A Thesis in

Curriculum and Instruction

by

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Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Doctor of Philosophy

May, 2005

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ABSTRACT

Understanding the Nature of Science (NOS) is an important objective of science for *all.* Researchers have proposed different strategies to teach the tenets of the NOS. Among the proposed strategies, most promising is an implicit and contextualized NOS teaching strategy, especially when consideration is given to the sociological NOS and the social constructivist view of science.

This study explores a group of college students' understanding of the NOS, with a particular emphasis on the sociological NOS understanding and the social view of science. The participants in this study completed an implicit and contextualized NOS instruction, a College Peer Review (CPR) project. The CPR project was designed to engage college students in an authentic scientific investigation through its original research, on-line collaboration, and peer review. The phenomena under investigation were students' conceptual ecologies of the NOS and their experiences with the activities of the CPR project.

The design of this investigation was a collective case study, it was instrumental with multiple cases. Five science education college students were purposively selected from a class of 21, all of whom participated in the CPR project. The primary data were collected through pre and post-interviews. A semi-structured NOS interview protocol designed by the researcher guided the interview conversations. The protocol questions searched for interviewees' understanding of the selected NOS tenets. Another semi-structured interview protocol was utilized to illuminate participants' experiences with the activities of the CPR project. The secondary data were collected through an on-line

philosophy of science questionnaire, before and after the CPR activities. Using another on-line questionnaire, participants' demographics and other relevant information were collected. The interviews' verbatim and participants' written responses were analyzed utilizing the constant comparative method. Within-case analyses were performed to identify participants' pre and post conceptions of the NOS and their experiences with the CPR project. The commonalities of changes in participants' conceptions of the NOS and their experiences with the project, derived from a cross-case analysis, were reported as the study findings.

The analyses revealed that students' understanding of the NOS were changed and in the sense developed, in favor of a more social constructivist view of science. The dramatic differences observed in participants' pre and post responses were in their conceptualizations of the sociological NOS. After the project was completed, participants portrayed science as socially constructed. Participants did not change their positions regarding the empirical, tentative, subjective, value-laden, and a human endeavor characteristics of science but they enhanced their arguments regarding the sociological NOS. It was expected that students would not change their positions regarding the aforementioned tenets of the NOS, because the project did not deliver some NOS ideologies explicitly.

The analyses of experiences with the CPR project revealed that participants mostly liked the original research and large scale aspects of the project. Participants found the on-line peer review aspect of the project unique. They reported that they would use a similar peer review system with their students when they begin teaching. Participants suggested not utilizing anonymous feedback, but making the reviewers known to the authors. According to the participants, providing eponymous feedback would improve the quality of the reviews. Better coordination of campuses to provide prompt feedback, the use of different organisms in addition to plant seeds, and second time experimenting were some of the other recommendations made by the students.

The sociological NOS is often not addressed in the research context of teaching about the NOS, though it lies on the border between the logical positivist and the social constructivist views of science. Peer review as commonly used in real scientific practice is an important aspect of science and it has the potential to illustrate to students how scientific knowledge is generated. Peer review is not currently taught in schools as part of the scientific method(s). An instructional strategy that draws upon the sociological NOS and peer review can provide meaningful insights in teaching and learning about science and the NOS. This study promotes teaching the NOS tenets through authentic scientific investigations. The research findings provide evidence that students develop an understanding of the sociological NOS when they are provided with opportunities to engage in the implicit and contextualized NOS instruction, in which the sociological NOS and authenticity of scientific practice guide the activities.

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I dedicate my dissertation thesis to my participants of this study. I would have never been able to pursue this study without their support, kindness, and honest participations. I learned many new things by their courage and willingness to participate.

I do want to thank my committee members for their endless support and the critical inputs to my work. Special thanks to William Carlsen and Wenda Bauchspies because of their inspirational thoughts on my work represented in this document. My wish is that everyone could have great supporters like I had during this project.

Chapter 1

Introduction

I conceptualize science teaching as having two distinct aspects. The first is teaching currently accepted scientific knowledge and its methods. The second is teaching the current philosophical, historical, sociological, and anthropological perspectives of science.

Scientific content knowledge and the method taught in schools reflect the current scientific paradigm. This is not a constant, static body of knowledge that was and will be valid for all times and locations of human existence. Within the continuation of humankind, because we are social beings, similar to all other social constructs that are subject to change, scientific knowledge is also subject to change and tentative in its nature.

Philosophical perspectives of science enlighten us as to why people in the past were interested in studying science, why they researched the questions they did, and what their expectations were concerning science. From dialectic syllogism to post-positivism, the scientific enterprise has been influenced by many different philosophies. Historical perspectives of science provide us with information on how the scientific enterprise was shaped and influenced by different worldviews. Sociological perspectives of science investigate the role that social maneuverings have played in both philosophies of science and the establishment of scientific content knowledge. Anthropological perspectives of science illuminate the role of scientific enterprise and its meaning for society.

1.1 Problem

Thomas Kuhn (1962, 1982) argues that what we teach in science as knowledge is persuasive and pedagogical. When we teach about science, we represent scientific content as a body of knowledge, which is valid and necessary whether students gather it through inquiry or through rote-memorization. On the other hand, as science educators we are conscious of the philosophical, historical, sociological, and anthropological perspectives of science. We are aware that current scientific knowledge is socially constructed and adapted to human life through technology. It has emerged from a tradition influenced by logical positivism, and shaped by the Renaissance.

The influence of science on human societies and individuals is more significant than ever before (Blades, 1997; Brickhouse, 1998; Cowan, 1998; Fuller, 2000; Hardings, 1991; Longino, 1990; Martin, 1998; McDermott, 1997; Mesthene, 1997; Schaff, 1998; Winner, 1997a). Not only our physical environment but also our moral and ethical values and our decision-making process have been shaped through scientific advancements and technological improvements (Barber, 2000; Bybee, 1993; Pinar, Reynolds, Slattery, & Taubman, 1995; Pojman, 1997; Shader-Frechette, 1997). If one of the major objectives of education is to nourish human goodness, then science education would be counter-productive if it were to hide the influence of scientific knowledge on human realities. Teaching science merely in terms of its content and method is to disregard the impact of science on society. A solid representation of scientific knowledge as it is currently accepted at that time and location promotes particular philosophies of science such as inductive reasoning, naïve realism, and logical positivism. Other philosophies of science should also be included in science teaching, especially when the objective is to liberate the society and increase conscientiousness (Freire, 1993). Hence, in addition to inductive reasoning, naïve realism, and logical positivism, students should also be informed about the institutionalization of science and the organization of scientific enterprise. Scientific content knowledge is not an explicit outside reality but is the product of the mutual agreement of scientists aligned with the current interests of society. Students learning science should develop critical thinking skills about the influence of the science on their own realities. Science educators have a duty to inform their students about the influence of scientific enterprise on human life, and to encourage them to be critical and to be responsible for the generation of scientific content knowledge. It is time for science educators to consider this responsibility in their teaching practices.

I believe science education should provide students with opportunities to develop their own understanding of science that will enable them to critically analyze scientific enterprise and its role in human society. Providing students with such a context requires science educators to revisit their teaching strategies. Whether science educators are helping students to develop a consciousness about the influence of science on their realities is an issue that guides the present study. Thus, an aim of this study is to search for a science teaching context that enables students to appreciate how the scientific enterprise functions and generates knowledge. The ultimate objective is to empower students with the ability to thoroughly analyze the impact of science on their daily lives.

1.2 Significance of the Study

In the science education literature there is a tendency to teach about the philosophical and historical perspectives of science and its enterprise (Abd-El-Khalick, Bell, & Lederman, 1998; Aikenhead & Ryan, 1992; Carey & Stauss, 1968; Clough, 1997; Dekkers, 2002; Gess-Newsome, 2002; Lakin & Wellington, 1994; Lederman, 1992; Liu & Lederman, 2002; McComas & Olson, 1998; Ravinder & Dana, 1997; Ryder, Leach, & Driver, 1999; Schwartz, Lederman, & Crawford 2000, among others). "Nature of Science" (NOS) instruction is a response to that tendency that has come about with the current interest in science education reforms (American Advancement of Association of Science [AAAS], 1989, 1993, 1997, 2001; National Research Council [NRC], 1996). "Science for all" appeals to some of the NOS instructional strategies that teachers can use for most students. Although many NOS instructional strategies (e.g., Gess-Newsome; 2002) based on philosophical and historical perspectives of science have been found pedagogically effective, they are not well-situated from a Sociology of Scientific Knowledge (SSK) perspective (Barber, 2000; Bauner, 2000; Fuller, 2000; Segerstrale, 2000).

My main critique of contemporary NOS instructional strategies (e.g., Abd-El-Khalick & Lederman, 2000a, 2000b; Akerson, Abd-El-Khalick, F., & Lederman, 2000; Khishfe & Abd-El-Khalick, 2002; Matthews, 1996) is that they do not provide a context for students to construct their own understanding of the NOS and to develop a sociological understanding of science. Most of those proposed NOS instructional strategies focus on teaching predetermined NOS tenets without questioning how and from where they are derived. Students are often presented with a set of NOS tenets that are partially derived from contemporary science philosophies. It is not a matter of whether contemporary philosophies of science and the tenets of NOS that have developed from those philosophies are valid; rather what is important is how students are presented with these ideas and the context in which they are taught. Sociological understanding of science is often lacking in many of those NOS instructional strategies. Probably this is because the context those strategies provide is not suitable to teach a sociological understanding of science. Sociological understanding of science (what I refer to as sociological NOS) are tenets of science derived from the SSK perspective.

The SSK program arose from the very backbone of the traditional sociology of science promoted by Robert Merton (1942, 1973, as cited in Segerstrale, 2000). From this newly emerging sociological perspective, science could not merely be justified philosophically and rationally. Thomas Kuhn (1962), in his essay, entitled “The Structure of Scientific Revolutions,” sent a liberating message that science does not always proceed through a rational logic; it also includes considerable irrational elements during times of scientific revolutions, when scientific paradigms change and scientists see the world in a totally different ways. Kuhn’s view called attention to the sociological aspects of scientific enterprise, adding to philosophical views, which had dominated science studies. The SSK program views science as a human endeavor, which enables one to perceive reality as human construction and understanding, rather than as explicit and absolute (Segerstrale, 2000). From the sociological standpoint, social interaction and mutual agreement signal the commencement of reality that is no more perceived as objective, static, and durable. The SSK program combines social constructivist and relativist orientations toward science.

For a thorough understanding of scientific enterprise, one should be informed about the sociological characteristics of science, in addition to philosophical and historical perspectives. The tenets of the NOS that best describe the scientific enterprise remain incomplete without a sociological perspective. That “science is empirical, subjective, tentative, value-laden, parsimonious, theory-laden, and a human endeavor” is an incomplete characterization of the NOS. Sociological characteristics of science should also be added to this list. However, communicating sociological NOS tenets requires more effort than simply transmitting compartmentalized understanding of the NOS, especially when a social constructivist perspective of science is given consideration. A study of students’ understanding of the sociological NOS is crucial to establish better strategies for teaching science in general, and teaching about the NOS in particular.

1.3 The Sociological Nature of Science (NOS)

The sociological NOS is rarely addressed in the tenets of science studied in the science education research literature. The sociological NOS draws from the work of the SSK program and its work in social constructivism. Because “constructivism” in general and “social constructivism” in particular have been defined differently in different places, I will first explain what I mean by “social constructivism.”

Constructivism has been accepted as a major theory of knowledge for the last three decades (Roth, 1995; Sismondo, 1993). Constructivism in its moderate form advocates that individuals do not passively receive knowledge, but actively construct it. Discourses of constructivism vary from one perspective to another (e.g., mild, radical, and social constructivism) and also from one context to another (i.e., science or mathematics education, or SSK). The terms "knowledge" and "construct" have different meanings when one talks about mild, radical, or social constructivism (Roth, 1995) and also different meanings in education or sociology. The construction process differs with the types of objects that can be constructed.

In an educational context, constructivism refers to a teaching method in which students construct their own understanding of the subject matter. From the mild constructivist perspective, the constructed knowledge is the individual's own understanding of the context she is experiencing and the subject of this process is the individual herself. She constructs the cognitive structures by using her senses. Her cognitive structures appear to correspond one-to-one with the objects found in the external world, that she can detect with her senses. The external world is perceived as a contingency, which is independent of the observer. Rather than the subject constructing the existence of the external world, she understands that observer-independent world.

According to Roth (1995), the mild constructivist view could not break down the objectivist and empirical philosophies. Radical constructivism is more convincing than mild constructivism because of the addition of two ideas. One idea is that radical constructivism views the function of cognition as adaptive rather than purely as constructive. The other idea is that cognition organizes the experiential world but disallows the discovery of objective reality (von Glaserfeld, as cited by Roth, 1995). Radical constructivism does not deny the existence of the external world, although it does deny that the world can be mirrored objectively by one's own knowledge. This means that knowledge, which is a self-organized cognitive process of the human brain, is not aimed at a true image of the real world but at a viable organization of the world as it is experienced (the viability criterion). In that sense the outside reality is not a matter of concern. Radical constructivism does not deny ontological and epistemological issues but neither does it take them for granted in explaining its theory.

Not all science educators agree with the radical constructivist presumptions of ontology and epistemology. For instance, Kelly (1997) points out that by ignoring ontology, radical constructivism mimics a positivist position, specifically the idea that the world is malleable to human thought. Even though radical constructivism suggests that subjects construct their conceptions through social interaction, it does not thoroughly address social factors in the establishment of scientific knowledge. The viability criterion does not concede the role of cultural heritage, theory-dependence of inquiry, institutional values, and shared language (Kelly, 1997). Also not addressed is the influence of the conceptual heritage of scientific discipline when people attempt to reconcile their conceptions with the new learned knowledge. Finally, radical constructivism does not deal with the authority of received ideas.

Social constructivism is a term often used in different contexts to explain different constructs and subjects of cognition. For instance, in the context of mathematical thinking theories, the knowledge that people construct is mental (internal) representations in cognition that are related to mathematical entities (Goldin, 1998; Sfard, 1992). From the standpoint of mathematical thinking theories, the term “social constructivism” brings to mind a perspective in which the interpretations of mathematical knowledge and its meaning are under investigation (von Glasersfeld, 1995). The similarities and differences of mathematical entities, their meanings for individuals, and their representations are questioned. In the context of SSK, the word "knowledge" means public knowledge, not the contents of an individual mind, as often perceived in mathematics and science education. Social constructivism in the SSK program is a perspective of science in which scientists are viewed as socially constructing knowledge of the external world, rather than uncovering it directly from Nature. SSK aligned with social constructivism advances a perspective that the organization of students in a classroom constitutes an important part of knowing and learning. In this study, I am referring to the SSK perspective in my use of the term "social constructivism." How scientific knowledge is generated through the social interactions of scientists, and how this knowledge is validated and mutually agreed upon is a characteristic of science that I term the "Sociological NOS."

1.4 Research Questions

This study explored the ways in which and the extent to which college students' conceptions of the sociological Nature of Science (NOS) are influenced by their participation with the activities of an innovative instructional design, the College Peer Review (CPR) project. The CPR project, in which a contextual and implicit NOS instructional strategy is implemented, has a particular design based on the sociological NOS. The sociological NOS was embedded within the activities of the CPR project: original research, on-line collaboration, and peer review.

Specifically, I explored changes in college students' conceptions of the NOS, giving particular attention to the sociological NOS. I sought to identify changes in students' conceptions of the sociological NOS so that I might determine "how" and “why” the CPR project influenced participants’ conceptions and beliefs about the establishment of scientific knowledge.

The main question of this study was as follows:

In what ways and to what extent are college students’ conceptions of the sociological NOS influenced by participation with the activities of the College Peer Review project?

To answer the research question, the following two sub-questions were posed:

1- How do college students’ NOS conceptions change after participating in the CPR project?

To answer this question, I first explored students’ conceptions of the NOS before and after the project. Later, I examined their conceptions of the NOS to highlight the differences.

2- What are college students’ experiences with the activities of the CPR project?

To answer this question, I identified participants’ experiences with the CPR project. I discussed the similarities and the differences of these experiences across participants.

The reason I investigated students’ experiences with the project activities was to identify the ways in which the system can be improved. This was not a planned or a systematic program evaluation. My interests were what students liked and did not like in the project, whether they had difficulties with any aspect of it, whether they would use similar systems in their teaching, and most important how we might improve the project in general and foster greater student involvement in future implementations of the project. The CPR project has multiple aspects and many additional components beyond the data collection and the subject selection aspects of this study. To evaluate this project, future researchers should interview not just the students who participated in this project but the course instructors and students in other institutions as well. All the documents and forms generated by the students should also be analyzed and appropriate observations should be conducted.

1.5 Organization of the Study

The theoretical underpinning of this study emanates from NOS instructional strategies and the SSK perspective. Because this study presents a challenge to conventional NOS instructional strategies, I first juxtapose the philosophical and sociological perspectives of science with the theoretical underpinnings of the conventional NOS instructional strategies, in which the tenets of NOS are taught explicitly. I develop an argument that explicit NOS instructional strategy makes misleading assumptions about the <u>nature</u> of the NOS. In the theoretical framework of this study, I address these neglected assumptions of an explicit NOS instructional strategy. To support my argument, I refer to contemporary philosophies of science and the SSK perspective.

Chapter 1 introduces the study through a brief overview. The need for the study, its significance, a description of a key term--“the sociological NOS”--and the research questions are presented in this chapter.

Chapter 2 reviews the relevant literature starting with a description of the major philosophies used to generate and validate scientific knowledge, and makes the case for teaching the NOS. In this study, my research questions focus on the sociological NOS as one component of a broader NOS. I consider the generation and validation of scientific knowledge as one of the core beliefs of the NOS. Merton (1982) asserted that students understand a phenomenon in ways that are similar to how their historical counterparts understood a phenomenon. Students' understanding of how scientific knowledge is generated and validated may resemble major philosophical explanations that can be found in history. Therefore, in Chapter 2, I will summarize the major philosophies of generating and validating scientific knowledge: dialectic syllogism, realism, positivism, logical positivism, Kuhn's and Popper's perspectives will be addressed. Although I do not claim that students' understandings of the establishment of scientific knowledge mirror sociological perspectives of science, I find it useful to discuss sociological perspectives of science. In this way, I establish a theoretical framework for my argument: Explicit NOS instructional strategy is misleading about the nature of the NOS, particularly when contemporary philosophies and sociologies of science are taken into consideration. In Chapter 2, following a discussion of the philosophies of science, sociological considerations are represented. Mannheim's sociology of knowledge, the Mertonian School, the Strong Program, and the Empirical School are all reviewed. Through these discussions, I highlight the implications that philosophical and sociological perspectives have for science education. For example, Kuhn's insights about philosophy and sociology of science may be implemented in texts used in science teaching.

Following a summary of sociological considerations, I discuss the different schools of thought addressed in science education literature concerning the NOS. Current science education reform documents stress that the NOS is a crucial subject in science education. Although there is a broad literature on teaching and learning NOS issues, there is not one definition of the NOS and one way to teach it. For example, according to Lederman (1992), the NOS refers to “the values and assumptions inherent to the development of scientific knowledge” (pp. 331). Others emphasize “science for all” perspectives that stress understanding how scientific knowledge is used and the role of science in addressing environmental and other social and technological problems. In Chapter 2, I also discuss how accepted definitions of the NOS are central to the issue of how scientific knowledge is established and validated. I provide evidence from the sociological perspectives of science that the explicit NOS instructional strategy misrepresents NOS. I attempt to conceptualize scientific literacy and the NOS in terms of critical thinking and multiple perspectives. After I categorize the NOS instructional strategies as discussed in the literature, and describe their strengthens and weakness, I present the merits of an implicit and contextualized NOS instructional strategy as a means of promoting critical thinking and multiple perspectives.

In Chapter 3, I describe the context of this study: the CPR project. This chapter has three main sections. First section addresses the features of “authentic scientific investigations” -- a unique characteristics of the CPR project-- and builds a framework that distinguish the practices of “getting ready to do science” and “doing science.” Next, the CPR project activities are described in reference to the participants’ engagement. How the CPR project encompasses characteristics of an authentic scientific investigation are addressed in this section. The third section summarizes critiques of peer review as commonly used in real scientific practice.

In Chapter 4, the methods of the study are represented with a description of the research design, participant selection, data collection, method of analysis, triangulation of data, and the role of the researcher.

In Chapter 5, the findings of within-case and cross-case analyses are represented. Because this is a collective case study (instrumental and multiple), in my analysis, participants' conceptualizations of the NOS are first studied separately. Participants' pre and post conceptions of the NOS are independently identified and changes in their conceptions are described. Next, I compare and contrast changes in participants' conceptions to identify commonalities. In response to the second research question of this study, participants' experiences with the CPR project are studied; again, first individual experiences are identified, then commonalities are presented.

In Chapter 5, the findings are summarized and the study limitation are listed. Recommendations are presented to inspire future studies. Study implications to science education and to professional development are addressed next. I also discuss some potential challenges when projects similar to CPR are implemented in earlier levels, particularly in childhood education. The document ends with a conclusion that presents a final remark.

Chapter 2

Theoretical Issues

> When I asked my interviewees “How is scientific knowledge being established?” they said that through experimenting “again and again.” Then I asked, “So after you conducted an experiment and stated your findings, how can you be sure that your claims are valid?” They answered, “Others should do the same experiment and find out the same results.” Experimenting was thought as the most basic step in the establishment of scientific claims, knowledge, and facts. (Yalvac, 2002)

2.1 Philosophies of Science

Until the 1970s, the philosophical considerations about science, were more apparent than any sociological considerations. Even Karl Mannheim (1936), who is known as the creator of the field “The Sociology of Knowledge,” excluded scientific enterprise from the rule that knowledge was in general influenced by social ideologies. Before talking about the sociological perspectives on science, it is essential to summarize retrospectively the basic philosophies that have shaped the human understanding of scientific knowledge. There are many categories that one may choose in explaining basic philosophies of science. Here, I contrast deductive and inductive reasoning because his distinction reveals many of the differences between science philosophies in regard to generating scientific claims, knowledge, and facts.

2.1.1 Deductive versus Inductive Reasoning

Stumpf (1966) defined inductive reasoning as “Proceeding from the observation of some particular facts to a generalization (or concerning) all such facts” (p.530) and deductive reasoning as “A process by which the mind relates the truth of one proposition to the truth of another by inferring that the truth of the second proposition is involved in and therefore derived from the first” (p.529).

Before the 17th century, the preferred method for generating and legitimating knowledge was based on dialectic syllogism, a method of argumentative logic (Milne & Taylor, 1998). In the process of establishing knowledge through the method of argumentative logic, the axioms found in authoritative texts were used as reference. Generally these texts were composed of the works of Aristotle, with commentaries by Greek and Arab scholars. By the use of the axioms, through deductive reasoning, true conclusions were generated and arguments for and against particular position statements were found. Experimentation was not required nor central to generate and/or legitimate the knowledge.

Experimentation and measurement are two catalysts of scientific knowledge, primarily legitimized by experimental philosophies. Inductive reasoning involves generating scientific knowledge through the application of argumentative logic in interpreting experimental results. For 17th century European experimental philosophers (e.g., Boyle, Hooke), inductive reasoning was considered the most appropriate practice in generating and legitimating scientific claims, knowledge, and facts.

In the 17th century, during the Renaissance, experimental philosophy proposed that inductive reasoning was the most appropriate method for generating and legitimating scientific claims, knowledge, and facts. Most of the thinkers of experimental philosophy (Bacon, Descartes, Galileo as cited by Stumpf, 1966) believed that human knowledge about the nature of things is available to anyone who uses the appropriate method in her search. Bacon was an important advocate of the philosophy of inductivism (Milne & Taylor, 1998). He argued that one must start from the senses and particulars, progress to middle axioms, to experimentation, and finally, to generating axioms. Galileo's construction and use of telescopes enabled experimental philosophers to recognize that not all theological facts are correct.

Bacon claimed that in order to understand the universe accurately, science should be free from revealed truths of theology and traditional knowledge (Stumpf, 1966). Contrary to dialectic syllogism, instead of looking back to the traditional and theological testimonies, Bacon, among other experimental philosophers, proposed establishing true knowledge by observing Nature and organizing the collected information into a system of axioms. In this new philosophy of science, there was a new method of observation and a new interpretation of Nature. In the process of generating knowledge, the emphasis was on observation, experimentation, and inductive reasoning. In experimental philosophy, the proponents of dialectic syllogism were mostly ignored.

Both deductive and inductive reasoning were considered as inquiry for the relations with God, the object, and the subject. Descartes (1642, as cited in Milne & Taylor, 1998) posited that knowledge of objects is formed in the mind, independently of the senses, mostly through deductive reasoning. This idealistic notion, that is, that human knowledge of the external world comes through the mind rather than through the senses, required “the existence of a God because His role was to be the final arbiter of the veracity of human thought” (Milne & Taylor, 1998, p.30). A realist position, contrary to the idealistic notion, argues a direct correspondence between the notion of an object and the object itself. Most 17th century experimental philosophers held realist views of science (Slaughter, 1982). Both idealist and realist philosophers included the existence of God in their arguments, but in different ways. Idealists supported the existence of God as the final arbiter of ideas, whereas realists believed that observations of the natural world provided a greater understanding of God’s creation. In the realist view, words and ideas were not the true picture of God’s creation, but a direct communication with the natural world through the careful use of senses. This argument initiated a rationale for experimenting and inductive reasoning.

2.1.2 Realism

From the realist perspective, human observations of reality correspond exactly to an external reality (Milne & Taylor, 1998). External reality is assumed as fixed and as behaving in a consistent way. Experiments that could be conducted over time and the data that could be collected as a result represent an unchanging reality. In that respect, the entire universe (the matter and the form of objects) should be structured and can come to be known by a finite number of objects.

Realist perspectives of science have three categorizations: naïve, experiential, and scientific:

1. Naïve realism views science as an attempt to explain an explicit, absolute truth of Nature.
2. Experiential realism perceives science as a relative truth in which the explanations may change over time and depend upon the instruments used, the methods applied, and the analysis conducted.
3. Scientific realism perceives science as an approximation of the absolute truth.

All of these realist perspectives hold the same assumption that there is an existing outside reality, which is objective and absolute. Their rapprochements vary but all project the same reality.

Through the institutionalization of relativist science, the Royal Society in England (*Philosophical Transactions*) placed emphasis on the use of plain and simple language to describe observations and experimental procedures. One of the objectives of promoting simple and plain language in scientific reports was to escape the ambiguity of daily language and the multiple meanings of metaphors. In regard to this interest by the Royal Society, some of the words that we also use in our daily language--'acid', 'apparatus', 'laboratory', 'gravity', 'lens', 'microscope'--were coined in the 17th century (Savory, 1967 as cited in Milne & Taylor, 1998). The hidden message of inventing and using the appropriate words for scientific enterprise includes an assumption that there is a direct relationship between a word and an object (Milne & Taylor, 1998). This kind of understanding views language as transparent and unproblematic as a tool in the interpretation of data generated from observations of the natural world.

Inductive reasoning involves the identification of scientific facts. According to the naïve realist perspective, matters of fact exist in Nature and can be discovered through experimenting, observing, and measuring. These matters of fact in Nature were considered as God's creation by the early realist philosophers (e.g., Boyle, 1660; Hooke, 1665, as cited in Milne & Taylor, 1998). Miller and Taylor (1997) observe that the belief of exploring God's creation through observing and experimenting remained consistent through the 19th century. In the late 19th century, positivism would challenge these assumed theological underpinnings of knowledge generation. In the 20th century, logical positivism would further advocate that the most reliable and accurate knowledge is established through the use of logic and direct observations of Nature.

2.1.3 Logical Positivism

Although Comte is known as the founder of positive philosophy, positivism is the general property of late 19th century philosophers (Stumpf, 1966). Positivism was initially proposed as a major solution to the problems of society rather than as a simply scientific way of thinking. Comte's initial interest was to reorganize the society he was belonging to. In late 19th century France, theological beliefs were no longer supporting a political authority because of Kant's, Hegel's, Fitche's, Goethe's, and Marx's influences on society. For Comte, no dictatorship would have succeeded if positivism had been accepted. He viewed the concepts of equality and demographic rights of humanity as metaphysical abstractions and dogmas. During the French Revolution, science was also gaining more authority than other fields. Through its spectacular endeavors, science challenged other ways of thinking (e.g., religion, free will, the value of metaphysics, and objective moral standards), which could not match the successes of science in their fields.

In order to reform both the society and the philosophy of the age, Comte proposed positive philosophy (positivism), a scientifically oriented philosophy.

Positivism as defined by Stumpf (1966, p. 356) rejects the assumption that nature has some ultimate purpose or end, and gives up any attempt to discover the internal or the secret causes of things. On the positive side, it attempts to study facts by observing the constant relations between things and by formulating the laws of science simply as the laws of constant relations among various phenomena.

In contrast to Comte's positivism, during the 20th century, the founders of the Vienna Circle (Carnap, Quine, Wittgenstein, Austin, and Rorty) willingly rejected metaphysics from their interest of analysis (as cited in Stumpf, 1966). Logical positivism perceived statements as meaningful only if they could be verified either directly or indirectly in experience. Logical positivism sought to analyze assertions (knowledge claims) that can be verified by empirical facts or logically connected to facts. The purpose of logical analysis was to discover the truth or falsehood of any given proposition. Therefore, the principal task is to discover a method of verification for a proposition. Method of verification could be either direct or indirect. A direct verification is a test of a proposition by a present perception (observable fact). An indirect verification requires a series of propositions in a logical sequence. A proposition, which is not directly verifiable, can only be verified by the direct verification of other propositions that are already empirically (or indirectly) verified. An empirically verified proposition is something that has an observable effect in the future. The application of logical analysis to metaphysical propositions is not verifiable and therefore logical positivism excludes them from its analysis. For a proposition to be empirical, it should depend upon experience. Anything that is expressive but lacking a predictable experience (such as laughing, lyrics, music, etc.) are rejected from the scientific domain.

In time, the goal of *verification* was shifted to *confirmation* in regard to Popper's, Lewis's, Nagel's, and Carnap's criticisms (Stumpf, 1966). Philosophers began to study under which circumstances a given proposition is valid and how one can confirm this validity. Metaphysics was not in the center of discussions, philosophers referred to the observable facts found in nature to discuss the validity of a given proposition.

Logical positivism maintains that the total content of a scientific theory lies in its implications for human experience (Shimony, 1991). In logical positivism, observations of Nature, experimentation, and the use of logic are the means of generating scientific knowledge. In this sense, the logical positivist view of science accepts the existence of objective reality outside the human mind.

2.2 Scientific Knowledge in Texts

The way science is taught in schools cultivates the logical positivist view of science in students' minds because it is taught as the reliable way of viewing the world and the most accurate method of explaining natural phenomena. The scientific method, mostly through inductive reasoning, is portrayed as the only, if not the most convincing way of discovering the objective reality. Most of the time, every level of schooling encourages the status quo of the scientific method without questioning its consequences. The currently accepted scientific conceptions are pictured as the static and constant explanations of natural phenomena.

Science education promotes a logical positivist view of science because of the way science is represented: through an authority of knowledge who has the power of ability to know. Since students try to understand the knowledge represented by the authority, they instinctively develop a conception that there is a body of knowledge outside of their minds and community that is not only valuable to learn but also fixed and static. Textbooks and text written explanations of scientific knowledge are for pedagogical considerations.

Kuhn (1962, 1982) claims that the aim of science textbooks is persuasive and pedagogic. When someone views science in the science textbooks, the scientific concepts become a body of knowledge, which is possessed as something valid, true, or necessary. From this point of view, the practice of science cannot be seen from the textbooks since its practice ends when someone writes the process in a textual form. What can be seen in the textbooks is what someone has decided scientific knowledge should be. Practicing science from the texts becomes somehow impossible. Kuhn (1982) believes that education perpetuates paradigms. He states;

> The objective of a textbook is to provide the reader, in the most economical and easily assimilable form, with a statement of what the contemporary scientific community believes it knows and of the principle uses to which that knowledge was acquired (discovered) and about why it was accepted by the profession (confirmation) would at best be excess baggie. (Kuhn, 1982, p.79)

Students accept theories on the basis of the authority of the teacher and textbooks, not because of evidence. Applications in books are not there as proof, but because solving them is part of acquiring the paradigm at the basis of current praxis. Textbooks only show the discoveries that have led to them and nothing of the sidetracks, or of earlier, alternative paradigms.

Teaching science and its enterprise from the logical positivist view initiates several sociological and cultural dilemmas. The existence of objective reality is one of the dangerous assumptions that logical positivism holds. It endorses and sanctions the existence of any dualities and dichotomies (e.g., good versus bad) originated from outside of the human mind. The dualities and dichotomies are being reified when one accepts that there is a reality outside of her mind. The reification of these dichotomies/dualities estranges the individuals as if they do not belong to the desired side of these dualities/dichotomies, and in some cases either of the sides. The assumption of the existence of objective reality and the scientific method as the means to discover that outside reality creates a duality: demarcation of pseudo-science.

Demarcation of science from pseudo-science is the ramification of the efforts of scientific discovery aligned with the logical positivist view of science. The demarcation problem of science is discussed within the context of inductive versus deductive logic. Logical positivism also accepts that science is progressive in its nature and approaches objective reality. Newly accepted (in logical positivist sense-discovered) scientific theories and paradigms are more sophisticated than their ancestors. Therefore, consequent theories and paradigms appear to be comparable because new ones are found more sophisticated than the old ones.

2.3 Kuhnian Perspective

The Kuhnian perspective was a response to the logical positivist view of science. Kuhn (1962) retrospectively discussed science and its enterprise. He viewed current scientific knowledge as a component of a scientific paradigm of that particular time. Revolutionary science occurs as if the old paradigm is no longer accurate to explain the related natural phenomena. Scientific theories accepted as tentative and subjective in their nature are claimed as incommensurable. In that sense, the progressive nature of science is denied, and so the existence of absolute truth is no more a matter of concern.

One of the key ideas of Kuhn’s essay, “The Structure of Scientific Knowledge,” is the incommensurability of scientific theories. Incommensurability of scientific theories is such a strong argument that even scientists concur with it. According to Bauer (2000), Kuhn’s scenario of scientific revolutions complemented with the incommensurability of scientific theories, has found meaningful resonance with scientists. Incommensurability induces an understanding of reality, which is not seen as absolute, relative, or instrumental. This kind of reality overcomes the realist, relativist, and instrumentalist understanding of science. Kuhn describes incommensurability of scientific theories by exemplifying two languages.

Kuhn (1962) introduced a paradigm shift in scientific revolutions. He referred to the accepted paradigms related to specific fields of studies as different "schools." When a crisis in a school ends with a commitment that the old paradigm is shown to be inadequate with respect to the newly invented paradigm, revolution occurs (revolution does not necessarily refer to progress.) The existing theories, as well as the paradigms, before and after a revolution, are analogously referred to as different languages. Different languages have different vocabularies as well as a different discourse in terms of meanings as well as conditions of applicability. Therefore, before and after a scientific revolution, different theories or paradigms (similar to different languages), will have different signs, representations, or conceptions even though they may originate from the same phenomenon.

Kuhn used the language analogy to emphasize that theories and paradigms, before and after a revolution, are "incommensurable." Essential to mention here is that Kuhn argued that translation of languages is not impossible and learning a new language is not always incomplete. He implied that there will always be differences between discourse and the vocabularies of different languages. These differences, especially in the meanings or the conditions of applicability of words, will always exist regardless of how well a bilingual speaker succeeds. Not only Kuhn, but also linguistics agree that the one-to-one correspondence of the translation of words is unachievable. From this point of view, any translation is always incommensurable. The difficulty in translation is also valid for successive theories. Kuhn also implied in his analysis that “incommensurability" does not mean "incomparability." Comparison is always possible between two successive theories, or analogously between the two languages. In any case, communication is always possible.

Kuhn continued to talk about the probable obstacles that translators (and narrators) encounter. He clarified that if any error occurs in communication because of translation (or successive theories), later on, it is more difficult to identify whether the error is within the translation or something else. The narrator can be anyone who speaks in her own language about any constant. Kuhn asserted that historians of science and scientists can be two different narrators that talk about science, and so their speech becomes two different languages. These two different languages are incommensurable, but not necessarily incomparable or inconsistent.

Kuhn's advice for reducing the possible errors within the translations of two languages was to include discursive paragraphs explaining the meaning of the words for the people who use them. In the comprehension of two perspectives, he proposed that understanding the discourses of the writers is essential. In a science education context, according to Kuhn, the best way to teach two different successive theories is reading the original materials which best explain the reasoning of the scientists.

Kuhn exemplified “incommensurability” of two perspectives by referring to a critic of one of his colleagues, Popper. Kuhn said that Popper missed the point that Kuhn’s notion of paradigm had been understood differently. This difference was because of their language-nature learning to philosophy of science (Language-nature learning holds the assumption that we acquire laws of Nature together with a knowledge of meanings of words in everyday or scientific language). Because of living in different communities and having different educational backgrounds, two theorists' stimuli will be different from each other. The differences of the stimuli of theorists cause two theories that are originated from the same concept, possessing the same data, to be interpreted differently. The differences in these interpretations are incommensurable. Kuhn advised that within the communication of different theories, it is better to translate another’s theory into her own language and simultaneously to describe the world in which that theory or language applies.

In conclusion, incommensurability is a mismatch of the discourse used by different theorists, and it is somehow impossible to eliminate. It exists to the extent that each of us is a unique individual. Incommensurability also accepts that there is no absolute truth that an individual can achieve because, not only is each individual different from another, but also over time, perspectives will change for both parties. From this point of view, the assumption of explicit knowledge and the existence of an absolute reality, which are the underpinnings of realism, are denied. The differences in the interpretations of phenomena are not because of the different observers, in different instances, but because the discourse of the language as well as the context itself are different. This view contrast with the relativist understanding of science. The instrumentalist view of science accepts the progressive nature of science in terms of its usefulness and efficiency. Incommensurability of scientific theories explains clearly why a succeeding paradigm is not superfluous to an old one. In other words, the nature of science is not progressive. The reality that can be crafted in light of incommensurability can overcome the realist’s, relativist’s, and instrumentalist’s understanding of science.

2.3.1 The Dilemma between Popper and Kuhn

One discussions regarding the establishment of scientific knowledge concerning its verification process: inductive versus deductive. Popper (1959) discussed the problem of demarcation of science. In his essay "The Logic of Scientific Discovery," he defined the problem of demarcation as the attempt of positivism to determine and mark off a boundary of empirical sciences and metaphysical systems. According to Popper, the problem of demarcation also includes the problem of induction. He viewed induction as a dogmatic argument held by logical positivists and realists.

Popper (1959) posited that an attempt to distinguish science from pseudo-science is nonsense. Inductive reasoning, one of the underlying themes of logical positivism (as well as realism), is considered a main criterion that distinguishes scientific method from other forms of inquiry. Popper (1959) agreed that "'the problem of induction," which originated with Hume, is the problem of whether inductive inferences are justified, or under what conditions they are justified. After scrutinizing the problem of induction, Popper posed the 'problem of demarcation' to science and its enterprise.

Popper had clearly defined the problem of demarcation in his essay: "The logic of scientific discovery." When deductive versus inductive testing is compared, deductive testing was more successful than inductive testing in eliminating the demarcation lines between science and non-science. Popper, within his context, tried to come closer to a solution to his arguments. Popper advocated that all the ideas and even hypotheses and theories come into being deductively.

Both Popper and Kuhn were trying to find philosophical (in their critiques of each other's sometimes logical) explanations to the problem of demarcation and to the problem of induction. A disagreement between Popper and Kuhn is essential to address here. According to Popper, Kuhn was a relativist and according to Kuhn, Popper was a positivist.

Popper proposed the notion of falsification contrary to the logical positivist and realist understanding of induction. According to falsification, all scientific theories are potentially fallible in light of new observations or new interpretations of already existing data. In that sense, scientific theories cannot be derived, and so they cannot be proved through an inductive logic. They must be deductively stated, and then tested. In that respect, Popper thought that a logical positivist and realist understanding of inductive reasoning was misleading.

Kuhn criticized Popper partly because he did not specify the conventions that would reduce the logical positivists' implications about science. Kuhn asked, "What is falsification if it is not conclusive disproof?" He argued that Popper provided an ideology rather than methodological rules, and supplied procedural maxims. According to Kuhn, positivists' degree of verification is replaced by degree of falsifications, and consequently Popper’s argument becomes another positivist one, which accepts deductive reasoning rather than inductive reasoning.

Kuhn's criticism of "falsification" is meaningful. Kuhn was examining science more than a specific moment, and this gave him an advantage in his arguments. Investigating the history of science and retrospectively arguing about science were Kuhn's strong points. In order to illuminate the existing pattern, Kuhn did not choose to give meaning to science and its enterprise as independent constructs. The meaning that we should consider is in the structure of scientific revolutions (or a paradigm shift from Kuhn's perspective). Kuhn examined the scientific literature retrospectively, and tried to relate his findings to what he thought.

On the other hand, Popper's response to Kuhn's ideas was also thoughtful. Popper argued that Kuhn was using a kind of logic of discovery, that his arguments were not psychological or historical but logical. So according to Popper, Kuhn is a historical relativist, who implies logical themes in his writings. Popper explicitly stated that he was not a relativist, that is one who argues rationality using a common set of assumptions. (e.g., language).

Popper stated, "For the belief in inductive logic is largely due to a confusion of psychological problems with epistemological ones." Popper makes a good point, whereas Kuhn ignores the underlying reasons of demarcation. Popper stated that "All the problems can be dealt with that are usually called 'epistemological' by the analysis of deductive testing." From this point of view, he claimed that the problem of demarcation is the problem of finding a criterion, which would enable us to distinguish between the empirical sciences on the one hand, and mathematics and logic as well as "metaphysical" systems on the other hand.

Finding a criterion to distinguish between science and non-science will not solve the problem of induction, nor the problem of demarcation. Kuhn's response to Popper's support for deductive testing is valid. Promoting deductive testing, which is somehow contrary to inductive testing, is not a good approach. Falsification is another way of accepting that there is always a way to process verification. To falsify something implies that there is an absolute truth in addition to fallible truths. Kuhn disagreed with this idea. He explained the structure of science as a paradigm shift, which may be a more narrow approach to science. On the other hand, I believe that we should continue to think about what science and its enterprise mean to us. In conclusion, Popper’s and Kuhn’s arguments on the philosophical dimensions of scientific reasoning are valuable to consider, but incomplete for a thorough conceptualization of science and its enterprise. Giving philosophical consideration to science and its enterprise is essential to illuminating the underlying assumptions of scientific discovery. However, it is not adequate from a sociological perspective.

2.4 Sociology of Scientific Knowledge

The sociology of science views science as a human endeavor, which enables one to perceive reality as human construction and understanding, rather than as explicit and absolute. From the sociological standpoint, social interaction and mutual agreement become the commencements of reality in which the reality is no more perceived as objective, static, and durable (Barber, 2000; Bauner, 2000; Fuller, 2000; Segerstrale, 2000; among others).

Karl Mannheim (1893-1947) is known as the founder of the sociology of knowledge. Even though Mannheim is mostly responsible for initiating the sociology of scientific knowledge, in his approach, he explicitly excluded universal forms of knowledge (science and mathematics) from the sociology of knowledge by assigning them a privileged and independent category (Barber, 2000; Fuller, 2000). In “Ideology and Utopia,” Mannheim viewed logic and mathematics so impersonal and objective that their sociological analysis would be irrelevant (Bloor; 1982).

The Sociology of Scientific Knowledge (SSK) arose from the traditional sociology of science promoted by Robert Merton (1942, 1973 as cited in Segerstrale, 2000). Merton presented his sociology of science in 1942 in opposition to Soviet and Nazi claims that the character of science was determined by the class or race of the people practicing it, and hence scientific validity was directly tied to some form of cultural superiority (Fuller, 2000). Merton ascertained the insider's account of science with norms and values to defend the excesses of totalitarian regimes. From the Mertonian view, science was treated as another social system. According to Fuller (2000), the well-known Mertonian norms of science, which are universalism, communism, disinterestedness, and organized skepticism, constitute the self-conscious realization of liberal democracy.

Up until the 1970s, attempts to explain science and its knowledge had mostly philosophical and rational dimensions. After 1970, sociologists and feminists started to scrutinize scientific knowledge and its rationality in light of social as well as cultural dimensions. From this newly emerging sociological perspective, science could not merely be justified philosophically and rationally; there was also a social factor.

Thomas Kuhn, in his essay entitled "The Structure of Scientific Knowledge," sent a liberating message that science does not always utilize a rational logic; there are considerable irrational elements during times of scientific revolutions and scientific paradigm changes to see the world in a totally different way. This view has perpetuated the sociological aspects of scientific enterprise, along with the philosophical views, which had dominated the field for centuries. Many sociologists of science welcomed the new research frameworks proposed by the Strong Program (promoted by a group at the University of Edinburg) and The Empirical Program of Relativism (promoted by Harry Collins and others at the University of Bath) (Segerstralle, 2000).

In the 1970s, the Strong Program movement came from the University of Edinburg in London, and then spread to Germany, Holland, France and also to the United States (Barber, 2000). The Strong Program was a sociological response to philosophical and historical explanations of the rationality of science. The commanders of the Strong Program (e.g., Bloor, Barnes, Edge, Mulkay, Pinch, Shapin, among others) studied specific instances for how societal influence played out in the elucidation of reliable scientific knowledge (Bauner, 2000).

The Strong Program pioneered a new sociological understanding of scientific knowledge that the Mertonian School and Mannheim did not. A missing element of the Mannheim's perspective that the Strong Program recognized was the value of relying on rationalist philosophy, rather than criticizing science as social interest. A ramification of this rationalist philosophy that the Mertonian School held was that certain forms of universals had been excluded from the social analysis. For instance, David Bloor (1982) argued that even mathematics and logic are social constructions. Bloor (1982) stated that one of the central problems of the sociology of knowledge was the status of logic and mathematics. As mentioned earlier, in the sociology of knowledge, from Mannheim's perspective, because they were considered impersonal and objective, logic and mathematics were excluded from the object of analysis. Bloor posited that Wittgenstein's Remarks on the Foundation of Mathematics challenged Mannheim's problematic assumption on the status of universals, and so logic and mathematics can no longer be viewed as impersonal and objective, but as some other social constructs.

The SSK also questioned Mertonian norms of science. The argument was that the counterparts of the proposed norms were also found in scientific practice. The Mertonian and Mannheim perspectives were both insufficient for a thorough analysis of science in social context.

Even though the Strong Program added new perspectives to the SSK that Mertonian and Mannheim initiated, sociologists are not completely satisfied with these analyses (e.g., Barber, 2000; Bauner, 2000; Fuller, 2000; Segerstrale, 2000). Barber (2000) argued that the commanders of the Strong Program had a relativist position in approaching the SSK. He claimed that we do not need to be ontological relativist about science and its development.

The SSK represents social constructivist and relativist orientations toward science. In the beginning of the 1970s, sociology and the history of science explicitly promoted the idea that science was sociologically constructed in light of the emerging views of the SSK (Segerstrale, 2000). Constructivist and relativist approaches postulated that scientific claims, knowledge, and facts were epistemologically superior to the other truth claims. Science was perceived as one of many ways of knowing the world, all of which could be explained with social factors.

Social constructivism argues that scientific facts themselves are socially constructed. What counts as facts is a matter of convention or contextual factors rather than of inherent scientific necessity. In that sense, science could be legitimately reduced to a power game (Segerstralle, 2000). Scientific convictions of scientists could also be problematically reduced to social and political interests. The new interdisciplinary field of social studies of science moved into an increasingly constructivist direction. Cultural studies and women’s studies that developed in the same intellectual milieu have chosen science as one of their primary objects of analysis. For instance, feminist science is interested in studies of the Western bias of science and its inherent masculinity (Harding, 1991; Longino, 1990). Feminist analyses are primarily focused on values and ideology

(Segerstralle, 2000), and not merely political, cultural, and personal ideology. Science itself was seen as inherently as value-laden. According to Harding, the very idea of objectivity became a masculine conspiracy. Rhetorical studies examined the rhetorical strategies of scientists. Literacy criticism, inspired by postmodernism, started treating science as one of many “texts” to “deconstruct” (Segerstralle, 2000).

2.5 School Science in the Continuum

The naïve realist perspective dominated the 17th century experimental science philosophies. Milne and Taylor (1998) argued that naïve realism as proposed by the 17th century realists is responsible for the way science is represented in schools. The belief that students can see scientific facts by looking outward at Nature-- through the textbook, the blackboard, the teacher, and the experimental apparatus rather than inward at their own conceptions-- is a ramification of naïve realism.

Miller and Taylor (1997) stated two myths of scientific knowledge derived from the naïve realism. “(1) Our observations of reality correspond exactly to an external reality, (2) Scientific facts do not depend on reason or opinion, have ethical as well as intellectual status, and a certainty not possessed by scientific theories” (1997, pp. 31-34). These myths also are the basis of an objectivist belief in which absolute true knowledge exists externally of the knower.

In school science, two extreme positions can be observed: naïve realism and instrumentalism. Hodson (1991) mentioned that in school science, naïve realist and instrumentalist philosophies of science are explicitly represented to students (1991, pp.

31-34). Even though in light of new data or a new way of interpreting existing data, we modify or completely change our view, when we teach science, we pretend that scientific theory provides a true description of world. We portray a naïve realist perspective of science per se scientific propositions have a real existence. In instrumentalism, the real world is described by means of imaginary scientific models. Theories are not true descriptions of Nature but they are valuable in terms of their usefulness in prediction, rather than because of their ontological validity.

In school science, there is too much emphasis on inductive methods, a too ready acceptance of an instrumentalist view of scientific theory. Hodson (1991) argued that the school science curriculum does not adequately address the complex relation between observation and theory and the activities of the scientific community in validating and disseminating scientific knowledge.

According to Kuhn (1982), our image of science and measurement are conditioned by the scientific texts. Kuhn scrutinized the meaning of measurement in the scientific method, and concluded that there is no agreement in any of the theories and experiments that propose an exact measurement. Almost always the application of a theory involves some kind of approximations (For instance, none of the plane is frictionless, the vacuum is not perfect, the atoms are not unaffected by collisions). Instrumental defects that can never be completely eliminated will influence the results of an experiment. Expecting a theory or an experiment to yield a precise result every time is a dogmatic situation. Even scientists distrust the findings when they recognize a perfect measurement each time.

Kuhn (1982) referred to scientists' expectations of a theory or an experiment not as an "agreement" but rather as a "reasonable agreement." For instance, in spectroscopy, reasonable agreement in measurement means agreement in the first six or eight left-hand digits in the numbers of a table of wave-length. On the other hand, in the theory of solids, two-place agreement is often considered specific. In that sense, reasonable agreement in measurement varies "from one part of science to another, and within any part of science it varies with time" (Kuhn, 1982, p.75).

From the current sociologist perspective of scientific knowledge, in school science, the realist, positivist, relativist, and instrumentalist perspectives are considered a naïve understanding of scientific knowledge. Milne and Taylor (1998) maintained that the image of science dominated by an objectivist epistemology is outdated and harmful.

2.6 Implications to School Science

Kuhn's (1962) incommensurability notion can be employed in science education. The incommensurability of theories can be represented by addressing the original writings of the scientists, in light of their cultural and social circumstances. Kuhn (1982) illustrated that there is no exact measurement in science; rather, the agreement of scientists is always a reasonable agreement. Even though students in science laboratories sometimes experience that there is no exact measurement in science, they may not recognize that this is also usual for scientists. Often in school science, when students conduct scientific experiments, their results do not match the textbook. Students, who find a different numerical result than the textbook, get confused in such a way that they think what they did is not correct. In teaching science, this anomaly can be used to support the idea that scientific data are not merely impersonal and logical, but also a negotiation of the community of scientists.

Constructivism focuses on the conceptual framework (in one's mind) rather than on the existing structure of the outside reality. From a critical constructivist perspective, all theories are subject to change in light of disconfirming observation. Constructivism urges science teachers to focus students' attentions on their own conceptual frameworks, and to use Nature as a testing ground for the viability of their conceptions, both old and new.

Milne and Taylor (1998) argued that students in schools should be "empowered through critical reflective thinking to understand the historical and cultural contingency and interconnectedness of the discursive practices of both science and school science" (p.45). When students become aware of the judgment standards of the scientific claims, knowledge, and facts, they will become aware of the prevailing framework of scientific enculturation. In that sense, the reality that they crafted will not be shaped merely by any specific philosophy or ideology (e.g., realist, constructivist, or any other) but will help them to understand and criticize the world they live in.

Science as a matter of practice and culture is a thoroughly social enterprise. Cobern (1998) posited that the learning of science must be viewed as a social construction, regardless of the nature of the scientific knowledge. He said that the excesses of scientism, technicism, and materialism should be avoided in science teaching. It is essential to encourage students to think of scientific enterprise from a broader perspective than merely a realist, a logical positivist, or an instrumentalist perspectives.

However, promoting only *one* perspective (e.g., social, constructivist, feminist, or cultural) that sounds most promising for a particular instance, should not be the main objective. When we revisit the development of sociology of science from the Mertonian school to now, it is apparent that even in the field of the SSK, there are multiple and controversial perspectives. Therefore, the healthiest standpoint is to promote as wide a perspective as we can, and be critical of our own personal arguments.

2.7 Scientific Literacy

One of the goals of science education is to achieve scientific literacy for all (American Advancement of Association of Science [AAAS], 1989, 1993, 1997, 2001; National Research Council [NRC], 1996). Scientific literacy is defined as "knowledge and skills in science, technology, and mathematics, along with scientific habits of mind and an understanding of the nature of science and its impact on individuals and its role in society" (Atlas of Scientific Literacy, 2001, p. vi). The objective of the American Advancement of Association of Science aligned with Project 2061, is to achieve scientific literacy for all, including women, minorities, and the under-represented student population.

Individuals living in a democratic society should have a comprehensive and reliable understanding and thorough ability to assess the dynamics of the constructs that shape their every daily lives. Science is one of the influential constructs of modern human societies that has an impact on nearly all aspects of life. Scientific literacy attempts to address the need for a public understanding of science and its role in society.

Some science educators (Abd-El-Khalick, Bell, & Lederman, 1998; Blades, 1997; Brickhouse, 1998; Bybee, 1993; Deboer, 2000; among others) agree that scientific literacy must include knowledge of scientific content and science process skills, and in addition, an adequate understanding of the role science plays in daily life. The purpose of education is to inform students about the advantages and disadvantages of the constructs that shape their realities and make them conscious and critical of those issues. Therefore, teaching science should be considered not only teaching currently accepted scientific knowledge, but also teaching about the status quo of science and its enterprise.

Benchmarks for Science Literacy (AAAS, 1993) and Science for all Americans (AAAS, 1989) indicate that as people become familiar with scientific study and conclusions, they are more likely to react thoughtfully to scientific claims and less likely to reject them out-of-hand or accept them uncritically. When we consider the impact of science and technology on human realities, this critical decision-making ability of citizens becomes noteworthy for the survival of democratic societies.

Students' understanding of science and its enterprise are essential for critical analysis of the consequences of science and technology. Lack of understanding of science and its enterprise may affect students' decision-making processes about critical scientific and technological issues.

2.8 Students' and Teachers' Views of the Nature of Science (NOS)

Science education researchers have an interest in studying students' conceptualizations of the Nature of Science (NOS) for the sake of achieving scientific literacy (Abd-El-Khalick, Bell, & Lederman, 1998; Akerson, Abd-El-Khalick, & Banning, 2002; Carey & Stauss, 1968; Clough, 1997; Gess-Newsome, 2002; Lakin & Wellington, 1994; Lederman, 1992; McComas & Olson, 1998; Ravinder & Dana, 1997; Schwartz, Lederman, & Crawford 2000, among others). Many of the studies (e.g., Dekkers, 2002; Bloom, 1989; Ryder, Leach, & Driver, 1999) investigated students' and teachers' understanding of science by designing reliable and valid instruments (e.g., Aikenhead & Ryan, 1992). Some of the researchers (e.g., Abd-El-Khalick et al., 1998; Akerson et al., 2002; Clough, 2001) have implemented and examined the effects of different instructional strategies aimed at teaching the NOS issues.

Lederman (1992) reviewed the earliest research done in assessing students' views of the NOS (e.g., Klopher & Cooley, 1961; Korth, 1969; Rubba, 1977; Wilson, 1954, among others). He summarized that in many of the earlier studies it was apparent that students believe scientific knowledge is absolute and the role of scientists is to discover the absolute truth.

Similar research assessing students' views of the NOS have been done with prospective and in-service science teachers. Lederman (1992), Behnke (1961), Miller (1963), Schmidt (1967), Carey and Stauss (1968, 1970), and Kimball (1968) have concluded that science teachers have conceptions that are similar to their students' and these are not adequate conceptions of the NOS. In the international context, research on students' and teachers' conceptions of the NOS reported similar findings (Dekkers, 2002; Khishfe & Abd-El-Khalick, 2002; Liu & Lederman, 2002; Yalvac & Crawford, 2002).

The aforementioned studies demonstrate that both teachers and students do not have an adequate understanding of science and they are also not well informed about the role of science and technology in society. These studies reported that students and teachers have not only weak, but inconsistent conceptions of the NOS. This raises the question, "*Is* there a consistent conception of the NOS?" This question suggests a need to define the NOS in a way that leads to consistent understandings among teachers and students.

2.9 Dilemmas on the Definitions of the NOS

The definition of the NOS is open ended. An investigation of the literature reveals that there is no one definition of the NOS (e.g., Alters, 1997; Lederman, 1992; Stinner & Williams, 1998). Some people choose to agree on various tenets and particular characteristics of the NOS. These tenets and characteristics are not completely contradictory to one another and different combinations of them do not create different poles. They are neither incorrect nor false. However, the chosen list may guide the researchers' interest to different viewpoints. Researchers' expectations diverge regarding students' and teachers' understanding of the NOS.

Lederman is commonly cited as one prominent NOS researcher. His stand on the NOS reflects tenets and characteristics of the NOS that most science education researchers agree upon (e.g., Akerson et al., 2002; Abd-El-Khalick et al., 1998; Akerson, Abd-El-Khalick, & Lederman, 2000; Dekkers, 2002; Aikenhead & Ryan, 1992; Smith & Scharmann, 1999). According to Lederman (1992), the NOS refers to the values and assumptions inherent to the development of scientific knowledge. One's conceptions of the NOS are one's beliefs about science and its enterprise. These beliefs include whether science is tentative, empirically based, theory-laden, parsimonious, subjective, value-laden, or a product of human endeavor or human creativity.

Schwartz, Lederman, and Crawford (2000) described the characteristics of the aforementioned features of the NOS that are often accepted and utilized by the science education community. Tentative characteristics of science explain that scientific knowledge is subject to change with new observations, discoveries, and reinterpretations of existing observations. Empirical characteristics of science explain that scientific theories and claims originate from observations of the natural world. Scientific knowledge consists of scientific theories and claims. Since humans are the actors of observing nature and establishing theories and claims, science is a human endeavor, and therefore influenced by the culture in which it is practiced. Multiple perspectives may contribute to multiple interpretations. Ethics, values, agendas, and prior experiences of cultures and/or scientists influence the development of posed questions, hypotheses, data collection procedures, and their interpretations. Scientific knowledge cannot achieve complete objectivity and will always be subjective.

Science educators have a tendency to categorize features of the NOS as the expected conceptualization for science students. In many science education studies of NOS issues, the discussion sections focus on the adequacy of students' conceptions. The adequacy of one's conception is measured by the degree to which students believe that science is tentative, empirically based, theory-laden, parsimonious, value-laden, and a product of human endeavor and human creativity. The expectation of students' and teachers' conceptions is in favor of these features of the NOS.

Many of the instruments assessing teachers’ and/or students’ conceptions of the NOS were developed from the science educators’ perspectives (Lederman, 1992). These perspectives are generally imported from contemporary science philosophers’ views of science and its enterprise (e.g., Kuhn, 1962; Lakatos, 1970; Popper; 1959). However, not all of the researchers agree that science philosophers are in accord concerning an identical list of the NOS features.

Alters (1997a) chose to develop a NOS instrument from the perspectives of science philosophers. He introduced the purported tenets of the NOS in the science education literature. He reported that 176 philosophers of science did not agree on a single definition of the NOS. Indeed, he argued that those philosophical standpoints often contradicted one another. In his study, Alters (1997a) addressed the views of philosophers with regard to their view on science education's NOS tenets. Findings indicate that there are 11 fundamental philosophies held by today’s science philosophers. In that respect, there is no one agreed-upon philosophical position underpinning the existing features of the NOS. Alters (1997a, 1997b) also did not agree with the tenets of the NOS that many science education researchers accept. His study revealed that philosophers of science express major criticisms of some of the basic science tenets and that different philosophers of science vary in their views about the tenets of the NOS. Alters also concluded that science philosophers and science educators did not completely agree on the same tenets of the NOS. He recommended that many of the NOS tenets, which are commonly taken as factual, be reconsidered in light of his study so that new criteria may be developed for future research.

Science education researchers (Abd-El-Khalick & Lederman, 1998; Akerson et al., 2000; Schwartz & Lederman, 2002) also accept the evolving nature of the NOS tenets. Abd-El-Khalick and Lederman (1998) posit that the NOS conceptions have changed throughout the development of science as has systematic thinking about it. Akerson et al. (2000) claim that the conceptions of the NOS are tentative and dynamic, subject to change. Hence, one may question the validity of any closed-form test of the NOS.

2.10 Emerging Critiques of Scientific Literacy

Shamos (1995) introduced a controversy in the science education literature related to the issue of scientific literacy for all. His concern focused on the questions that science education reform documents (AAAS, 1989, 1993, 1997, 2001; NRC, 1996) pose in their attempts to define scientific literacy. According to Shamos, the question is not which science to teach, but rather why it should be taught. Reform documents portray scientific literacy as a level of cognition that practitioners should achieve. Science education reforms have been found ineffective in teaching scientific content and science process skills to the public (Shamos, 1995). Not all members of the public can be knowledgeable about scientific content and have science process skills as the advanced level of scientists. Only a small fraction of the population is (and can be) scientifically literate in terms of the expectations of reform documents, that is, scientific content knowledge, science process skills, and “an” understanding of the NOS.

Shamos (1995) proposed a new definition of scientific literacy, making it feasible to achieve. According to his definition, for an individual to be scientifically literate, she should know what science is about, have an awareness of how it works, understand what can be expected from it, and know how she can best express herself in social-scientific matters. To achieve scientific literacy for all, Shamos (1995) suggests that educators

> (a) introduce *all* topics through some relevant problems or issues in technology, but only where these are meaningful to students; (b) work back to the underlying science where, and only to the extent, it is needed to account for the technology; (c) use the underlying science, where appropriate, as a springboard to discuss the nature of the scientific enterprise—namely, the role of experiment and the meaning of scientific truth, facts, laws, theories, etc.; (d) return to technology, again where appropriate, as the basis for discussing the science/society interface; and finally (e) conclude with when and how to use expert advice at the science/society interface. (Shamos, 1995, pp. 225-226)

Shamos recommends that the focus of instruction be technology, which he views as a bridge between science and society. This kind of instruction leads to discussions about the sociological perspectives of science in science education classrooms. Even though, technology focused instruction is a good start to initiate such discussions, it may not be adequate to address all the sociological issues related to science, for example feminist pedagogies (Brickhouse, 1998; Hardings, 1991). The status quo of science and the authority of ability to know could not be easily deconstructed with instructions merely derived from the technological issues. Additional instructional strategies should also be developed, and perhaps would be used to supplement, in order to encourage students to discuss how and why the ethical and the moral values of a society are shaped and/or preserved with science and technology.

Deboer (2000) mentioned a need to reconceptualize scientific literacy. He retrospectively investigated the important ideas related to the term scientific literacy and concluded that scientific literacy is about public understanding of science. In that conceptualization, public understanding of science is tentative, open-ended, organic, and not static, and that therefore there is no static way to assess it and determine that it is achieved.

> … instead of defining scientific literacy in terms of specifically prescribed learning outcomes, scientific literacy should be conceptualized broadly enough for local school districts and individual classroom teachers to pursue the goals that are most suitable for their particular situations along with the content and methodologies that are most appropriate for them and their students. This would do more to enhance the public's understanding and appreciation of science than will current efforts that are too narrowly aimed at increasing scores on international tests of science knowledge. A broad and open-ended approach to scientific literacy would free teachers and students to develop a wider variety of innovative responses to the call for an increased understanding of science for all. (Deboer, 2000, p. 582)

Recognizing the interrelations among science, technology, and society should be the basic requirement for scientific literacy. Merely knowing about scientific content, having scientific process skills, and having a consistent understanding of currently accepted features of the NOS will not be adequate to analyze thoroughly the role of science and its interaction with society.

2.11 Emerging Critiques of the NOS

Most contemporary science education reform documents, standards, and benchmarks (AAAS, 1989, 1993, 1997, 2001; NRC, 1996) have an interest in teaching what the NOS is and what students and teachers should know about it . Research findings advocate different strategies for teaching various features of the NOS. Some critiques (Blades, 1997; Brickhouse, 1998; Hardings, 1991; Smith & Scharmann, 1999; Turner & Sullenger, 1999) imply that both the conceptualization of desired student understanding of the NOS and related teaching strategies are problematic. The definition of the NOS found in reform documents is said to be inadequate and misleading because of its (a) attempts to demarcate science from non-science, (b) compartmentalization of the NOS issues, and (c) lack of interest in eliminating androcentric and sexist elements in scientific claims.

Turner and Sullenger (1999) discussed the basic assumptions of the NOS from science-education related national and international documents (AAAS, 1989, 1993, 1997, 2001; National Academy of Science; 1996; NRC, 1996). They argue that these documents present a traditional approach to the images of the NOS. The main criticism concerns how these documents demarcate science from non-science. Demarcation of science is inherently problematic from a philosophical standpoint (Popper, 1959). Attempts to demarcate science from non-science leads to an image of science, which does not represent a way of knowing, but merely a static and objective way of explaining the world. According to Popper, the demarcation of science is associated with the problem of inductive reasoning. Relying solely on inductive reasoning leads one to endorse the existence of objective reality. The logical and empirical characteristics of science in addition to its alienation from other ways of knowing identify the objective of scientific practice as a search for absolute truth. Therefore, any attempt to demarcate science reifies the existence of absolute, objective reality.

Brickhouse (1998) pointed out that Rutherford and Ahlgren (1990) ignored disagreement over fundamental issues related to science, technology, and the nature of scientific objectivity. According to Brickhouse, one of the recent science education reform documents, Science for all Americans (Rutherford & Ahlgren, 1990), only partially includes the NOS issues. She argues that Science for all Americans assumes that the nature of science and technology has been defined and compartmentalized as a subject matter.

Feminist perspectives on science and technology provide important feedback that should be included in science education curriculum. Feminist epistemologies of science attempt to eliminate androcentric and sexist elements in scientific claims. Rather than acquiring the subject matter (whether it is scientific knowledge or the NOS), a feminist science perspective endorses discussions of scientific and technological dilemmas in light of their embedded ideologies. Feminist epistemologies provide an important lens through which students can critically analyze the relationships among science, technology, and society (Harding, 1991). Brickhouse (1998) maintains that when science and technology are taught as problems that society encounters within multiple perspectives, students are more likely to respond and participate in discussions. Science teachers should teach in a way that their students will be gender-awareness in carrying out scientific processes. Neutralizing sex and identifying scientists without their gender can easily hide the androcentric and sexist elements already embedded in the scientific claims. To promote students' awareness of the androcentric and sexist elements in science, teachers should also address the race and the gender of the scientists and lead discussions of how and why any particular gender/sex/race might influence the proposed, as well as the legitimized, scientific claims. Science, from a feminist perspective (Harding, 1991), is claimed as not only belonging to male white scientists but also to women, people of color, feminists, lesbians, gays, and many others, that requires an awareness of multiple realities.

Philosophers' views of the NOS appear to be the most validated viewpoints of science. However, it may be unrealistic to think that science education students will understand and appreciate standpoints and tenets of the NOS that philosophers hold. Students' cognitive and social capabilities may not be adequate to comprehend thoroughly most of the philosophical tenets of the NOS that philosophers, and to some extent, scientists propose. Smith and Scharmann (1999) suggest that science educators propose more appropriate features of the NOS in their teaching practices to science education students, rather than simply modeling philosophers' and scientists' views of the NOS.

Smith and Scharmann (1999) claimed that neither the scientists' nor the philosophers' views of the NOS should be directly modeled when teaching the NOS to science education students, particularly in K-12 levels. Many scientists are so deeply engaged in their research programs and ill informed about the history and philosophy of science that they do not conceptualize a thorough understanding of the NOS. In addition, many scientists are found too engaged in the certainty of scientific knowledge, and ignore other ways of knowing. Demarcation of science from non-science is one of the implications of that fidelity. A similar trend is also observable in recent science education reform documents. Smith and Sharmann (1999) argued that the attempts to teach demarcation of science from non-science is misleading, because even the philosophers do not agree on the exact boundaries between science and non-science.

Smith and Sharmann (1999) proposed that in science education, teachers should teach about what is more or less scientific and what characteristic of it makes it scientific, rather than what is and what is not science. Evolution versus creationism is an example of teaching what is more or less scientific and why. To some extent, creationism may include scientific characteristics, so any attempt to demarcate it absolutely from science will be disingenuous. In addition, evolutionism also includes a non-scientific characteristic: an authority of power, that is, credibility of the scientists and the research paradigm. Smith and Scharmann (1999) also discussed teaching Popper's (1959) falsifiability of scientific theories. They mentioned that the falsifiability of theories may be beyond students' cognitive understanding; therefore, choosing to teach that tenet of the NOS to science education students may not be useful.

2.12 Teaching and Learning about the NOS

Science educators have proposed different strategies for teaching and learning the NOS. Some advocate the essence of teaching the NOS through scientific content and process skill instruction. Some of them (e.g., Matthews, 1996) advocate teaching the NOS through historical cases of scientific knowledge. Some others (e.g., Abd-El-Khalick & Lederman 1998; Akerson et al., 2000; Khishfe & Abd-El-Khalick, 2002) believe teaching the NOS can only be achieved with explicit NOS instruction.

In the early 1900s, the emphasis in teaching NOS issues was on the scientific method (Lederman, 1992). By the year 1960, the main emphasis had shifted from the scientific method to scientific process and inquiry. Recently, teaching and learning the

NOS is considered a prerequisite for scientific literacy (AAAS, 1989, 2001). Lederman (1992) also reviewed the earliest research done in designing and assessing the curricula to improve students' conceptions of the NOS. In their interventions, some of the researchers (Klopher & Cooley, 1963; Jones, 1965; Crumb, 1965; Yager & Welch; 1966; Gennaro, 1964; Sorenson, 1966; Ramsey & Howe, 1969; Aikenheid, 1979, as cited in Lederman 1992) found significant differences in students' conceptions of the NOS. Here, the focus of the implemented curriculum was on the laboratory activities and the history of science. On the other hand, some other researchers (Trent, 1965; Troxel, 1968; Jungwirth, 1970; Tamir, 1972; Durkee, 1974, as cited in Lederman 1992) reported that no significant differences were in students' conceptions of the NOS when the laboratory-focused and history of science emphasized curricula were implemented.

After the 1970s, more attention was given to the teachers' conceptions of the NOS. Yager (1966) and Kleinman (1965) as cited in Lederman (1992), concluded that the teacher was a significant factor in students' understanding of the NOS. Yager observed the effect of different instructors when the instruction materials and design were controlled. Kleinman reported that the teachers who asked critical thinking questions promoted better student understanding of the NOS than the teachers who asked fewer questions of this type. Teacher style was seen as an important variable in shaping the students' conceptions of the NOS and this notion can be observed in the future studies.

2.13 The Categorization of the NOS Instructions

Because researchers suggest different ways of teaching NOS, I found it useful to begin by categorizing possible approaches. My framework has two dimensions (Table 2.1). One dimension is about the context of the *instructional activity* students are engaged. Clough (2002, personal communications) categorized the context of NOS instructional activities as contextualized versus decontextualized. The other dimension is about the origin of *NOS understandings*, that is, where and how the NOS features are originated. Abd-El-Khalick and Lederman (1998), in their review of the attempts undertaken to improve science teachers' and students' conceptions of the NOS, discriminate along this second dimensions in terms of implicit versus explicit NOS instruction.

Table **2.1**: Nature of Science (NOS) Instructions

Nature of Science (NOS) Instructions	**Contextualized**	**Decontextualized**
Implicit	Scientific Activity + Embedded features of NOS	Un-scientific Activity + Embedded features of NOS
Explicit	Scientific Activity + Imported features of NOS	Un-scientific Activity + Imported features of NOS.

When students are engaged in scientific activities, that kind of NOS instructional strategy becomes contextualized. Scientific activities that make the NOS instruction "contextualized" are the practices similar to that scientist often experience in their routine work. For instance, "setting up a scientific experiment," "gathering data," "obtaining measurement," "making observations," "analyzing scientific data," "writing a scientific report," or "reviewing one another's scientific conclusions" are some examples of scientific activities. The purpose of those scientific activities relates to "doing science" rather than merely "learning about science". Decontextualized NOS instruction includes activities other than the scientific activities. For instance, "solving a puzzle that includes scientific definitions," "taking a science test," "watching an instructional (science) video," "reading scientists' biographies," or any other type of activities that scientists do not engage in their routine work. "Taking a science test" or "watching an instructional (science) video" is "decontextualized" because student work is not taking place within the context of scientific practice. (I note here that "decontextualized" contemporary activities are very common in school science, indeed, it is hard to imagine science classrooms without them. Whether a "contextualized" or a "decontextualized" approach is more effective in particular setting is an open questions).

The second dimension (implicit vs. explicit) is about how and where the NOS features originate in instruction. On this dimension, there are two ways for the features of the NOS to be initiated: explicitly or implicitly. In an "explicit" NOS instruction, particular features of the NOS are imported from outside into the classroom context. The instruction aims to represent pre-determined, formalized features of the NOS, mostly originated and organized from the instructor's point of view. Through class activities those features may be illustrated, but the interpretation of what those activities demonstrate (with respect to the NOS) is fully pre-determined and, preferably, unambiguous. Learners are expected to grasp the instructor's understanding of the NOS through the intervention. Consequently, there are both desired and undesired understandings of the NOS. If students' understandings of the NOS are consistent with the expectations of the teacher, then the intervention is successful. Otherwise, the instruction is deemed ineffective or unsuccessful.

In "implicit" NOS instruction, even though the instructor may have particular expectations of how students' understandings of the NOS will be shaped by instruction, the actual understandings of the students are allowed to emerge from their participation in the instructional activity and the context itself. Even though, instructor is welcomed to initiate discussions about the NOS, she does not expose an end understanding of the NOS and her intent is more to encourage students to think rather than to decide. The instruction does not particularly aim to represent pre-determined and formalized NOS tenets, but it rather aims to lead students to conceptualize. In this kind of instruction, students are free to construct their *own* understanding from their *own* experiences with the intervention. They may conceptualize features of the NOS that is or is not in accordance with the instructor's expectations or they may not develop any kind of conception.

Table 2.1 summarizes the juxtaposed dimensions of the NOS instructions. In an *implicit contextualized* NOS instruction, the activity is basically scientific and the students' understanding of the features of the NOS is open-ended. Instruction does not explicitly stress any particular aspects of the NOS, at least by design. In an *implicit decontextualized* NOS instruction, the activity can be any kind of activity other than a scientific activity, and again none of the features of the NOS is imported from outside into the classroom context in the form of curriculum objectives. In an *explicit contextualized* NOS instruction, a scientific activity is coupled with imported features of the NOS, which are represented explicitly throughout the intervention. In an *explicit decontextualized* NOS instruction, tenets of NOS are pre-determined by the teacher and taught with activities other than scientific.

2.14 Paradoxical Assumption: Explicit and Decontextualized NOS Instruction

Implicit NOS instruction has been found ineffective by the researchers who advocate the essence of explicit NOS instruction (e.g., Akerson, et al., 2000; Abd-El-Khalick, Bell, & Lederman 1998; Bell et al., 2000; Gess-Newsome, 2002; Lederman & Abd-El-Khalick, 1998; Matkins, Bell, Irving, & McNall, 2002). These researchers have focused their investigations generally to an explicit and decontextualized NOS instructional strategy.

For instance, Akerson et al. (2000) assessed the influence of an explicit, reflective, activity-based approach to NOS instruction in the context of an elementary science methods course. In that explicit (decontextualized) NOS instruction, researchers targeted the empirical, tentative, subjective, theory-laden, imaginative, creative, social, and cultural features of the NOS. The intervention encompassed instruction in an activity-based explicit NOS and in related classroom discussions, both of which were not necessarily related to scientific knowledge. Throughout the instructions, the current views of the NOS were explicitly imposed in inquiry-based activities, readings, film clips, and class discussions. (Akerson et al., 2000).

Abd-El-Khalick et al. (1998) and Bell et al. (1998) mentioned that their instruction emphasized an explicit approach to the NOS instruction, but not a didactic method in teaching NOS concepts. Their intervention was an explicit decontextualized NOS instruction. They chose to import current views of the NOS from outside into the classroom context by making them explicit throughout the instruction. The activities they implemented were not scientific activities, but other kind of activities, which attempted to teach particular views of the NOS and with little emphasis on scientific content.

Researchers (Abd-El-Khalick et al., 1998; Akerson et al., 2000; Bell et al., 1998; Lederman, 1986; Lederman & Druger, 1985) have reported that their analyses show that an explicit and reflective NOS instruction was effective in changing students' views in favor of targeted features of the NOS. Lederman (1986) and Lederman and Druger (1985) also reported that purposeful instruction (mostly through explicit decontextualized NOS instruction) is effective in developing better conceptions of the NOS. These arguments have two hidden messages. The first message is that there are "better" (or "consensus") conceptions of the NOS. The second message is that the objective of instruction is to help students assimilate particular conceptions of the NOS, but not to help them develop critical thinking skills so that they will analyze and assess these conceptions.

I believe that this kind of instruction, which is explicit and decontextualized, is contradictory to the *nature* of the NOS. It is problematic and paradoxical in terms of how reality is pictured. Explicit NOS instruction encompasses a pre-determined understanding of the NOS ready to be imposed onto students. By doing so, the existence of objective understanding of the NOS is reified and legitimized. Importing pre-determined NOS conceptions pays little attention to students' own understandings, as well as their multiple perspectives on science and technology.

The model of implicit contextual NOS instruction potentially embraces multiple perspectives of science and technology. In contrast to explicit and contextualized NOS instruction, from the very beginning of an implicit contextual NOS instruction, potential understandings of the NOS are left to students to construct. Students have a chance to establish their own understanding through their experiences, rather than simply importing them from outside. Any imported ideology from outside runs the risk of reifying the explicit knowledge assumption, suggesting the existence of absolute, objective "reality" about what the NOS is. An implicit contextualized NOS instruction is more likely to be receptive to students constructing their own understandings. It also embraces multiple perspectives in conjunction with students' multiple realities, which may be a good objective in teaching the NOS.

Reform documents (e.g., AAAS, 1989) mention that stories from the history of science, biographies, and books about scientists would be helpful in teaching the NOS. They recommend that early Egyptian, Greek, Chinese, and Arabic cultures' enhancements regarding the development of scientific knowledge be included in the textbooks and written materials. It is difficult to see how explicit decontextualized NOS instruction could adequately address the cultural and historical aspects of science and its enterprise, absent of historical congruence with the tenets.

Matthews (1996) maintained that the history and philosophy of science are essential components of science teacher preparation programs. His assumption is that when teachers know more about the "constructivist, positivist, realist, feminist, Marxist, multiculturalist or universalist nature of science, their students will better embrace constructivist, positivist, realist, feminist, Marxist, multiculturalist or universalist nature of science" (Matthews, 1996, p. 994). Matthews also suggested that the best approach to teach the NOS would be in inductive and tentative manner, but not didactic. In other words, students' understanding of the NOS should derive from the context itself rather than being imported from outside into the context. In that sense, the features of the NOS can arise "from questions about, and discussions of, episodes in the history of science, from biographies of scientist, from laboratory exercises including ones that replicate historical experiments, from textbooks illustrations, from popular writings or from science-related social issues" (Matthews, 1996, p.995).

2.15 Revisiting Scientific Literacy

Science and technology are dynamic and operational constructs. Scientific advancements generate new technologies and technological innovations engender scientific knowledge. The dynamic and operational nature of science and technology constantly influence the components of society. Technological advancements influence and sometimes create new values (Cowan, 1998; Martin, 1998; Scharff, 1998). Technology has a great impact on how we construct our identities (Mesthene, 1997; Winner, 1997a; Winner 1997b). Not only are the physical environments of our realities shaped by the scientific discoveries and the technological advancements, but our moral and ethical values are also influenced (Yalvac, 2001).

Science, technology, and values/ethics of society are three different but interrelated constructs of human societies. In addition to the impact of science and technology on human ethics and values, these in turn, also affect science and its enterprise (Brickhouse, 1998). The interplay of science, technology, and society is multiple. Therefore, the interrelations among the ethics and values of society, science, and technology should be conceptualized as multiple ways of interaction.

In order to understand the interrelationships among science, technology, and society, teaching science in schools should help students to develop their own critical thinking skills. For their own best interests, it is essential for students to be able to assess critically the effects of science and technology on daily life. An exclusive body of knowledge about science will not be adequate for a thorough analysis of the interrelationships among science, technology, and society. Students exposed to pre-determined and static critiques can only be effective in a limited period of time. When the dynamic and operational nature of science and technology are considered, the need for individuals' critical thinking skills becomes clearer.

There are crucial issues need to be addressed with the definition of scientific literacy as "knowledge and skills in science, technology, and mathematics, along with scientific habits of mind and an understanding of the nature of science and its impact on individuals and its role in society" (AAAS, 2001, p. vi). In this definition, the essence of students' critical thinking skills are implied however, they can be easily concealed if particular attention is not given. Having a particular understanding of the NOS and its impact on individuals and its role in society does not thoroughly address critical thinking skills. Indeed, it overestimates that having an understanding of the NOS along with scientific habits of mind is sufficient to develop critical thinking skills. Consequence of this overestimation is the attempts to teach the NOS tenets as a subject matter. Compartmentalizing the NOS tenets and sorting them out same as instructional objectives will make teaching the NOS easier for teachers. However, this is contradictory to the nature of the NOS, and discourage students to think critically on science related issues.

There is no "one" understanding of the NOS (Alters, 1997a, 1997b; Brickhouse, 1998; Harding, 1991; Matthew, 1998; Turner & Sullenger, 1999). Even science educators agree that the NOS is dynamic and tentative (Abd-El-Khalick & Lederman, 1998; Akerson et al., 2000; among others). If we teach an understanding of the NOS to the current generations then what will the future generations be teaching if our current NOS understandings will change? Therefore, a different strategy should be adapted in conveying the NOS issues to students. Students' multiple perspectives on the NOS should be welcomed. In attempts to teach new (or other) perspectives, students' own understandings and conceptualization of their experiences should be regarded, rather than our own judgments of the NOS and our expectations of student understanding.

As science educators, we are expected to teach scientific knowledge. As educators, we are expected to inform students for their own good. Science and technology are not considered direct threats to society, yet if their consequences for society are not critically assessed so that corrective actions are taken when needed, they may have a harmful effect on society. Having the ability to analyze science and its enterprise critically may help students to be aware of the possible risks of science and technology. When scientific literacy is re-visited, that is, when there is emphasis on critical thinking skills about the interrelationships among science, technology and society, the importance of developing multiple understanding of the NOS becomes clear. The intent in teaching about the NOS issues should be to ensure that students' critical thinking skills are aligned with that kind of multiple understanding of the NOS. In the next chapter, I describe an effort to create a context for learning science that provides students with such opportunities.

Chapter 3

Context: College Peer Review Project

3.1 Overview

In this chapter, I describe the context of the present study: the College Peer Review (CPR) project. The purpose of this study is to investigate the ways in which and the extent to which college students' conceptions of the sociological NOS are influenced by their participation with the activities of the CPR project. Therefore, a description of the CPR project and its major components will be helpful to the reader.

There are three main sections in this chapter. The first section presents a framework that describes the features of an authentic scientific investigation, which is a unique characteristics of the CPR project. The second section describes the activities of the CPR project and provides a rationale for their design strategies. The project activities can be summarized under three categories: (a) original research, (b) on-line collaboration, and (c) peer review. The intention of these activities was to engage college students in an authentic scientific activity. Therefore, this section also addresses how the CPR project encompasses authentic characteristics of scientific investigations.

As introduced in Chapter 2, my view is that an "authentic" scientific activity should not only include most of the fundamental elements of a "real" scientific activity, but also utilize "authentic" epistemologies. In an authentic scientific activity, students should play a meaningful role in generating the knowledge. The hope is that students will begin to own, create, and utilize the knowledge they create (Freire, 1993). Peer review is an essential component of the CPR project because it enables students to judge the quality of each other's work and construct a community of learners that is able to know. These features mirror the social (and epistemological) practices of real scientific communities. For example, in a real scientific field, "getting the answer" is not sufficient to establish a knowledge claim as fact. Review by peers is essential.

Peer review is not a completely innocent practice in which participants objectively negotiate the validity of one explanation among many (Nash, 1996). The peer review system as currently used in USA and in Great Britain has strengths and weaknesses (Mitroff & Chubin, 2003). It should be noted that peer review as practiced in science has not been thoroughly investigated. For instance, whether the double blind review is a better system than its counterpart has not been resolved. Therefore, in the third section of this chapter, I summarize the benefits and drawbacks of the peer review system as currently used in science.

3.2 Authentic Scientific Investigation

Basically, I view an "authentic scientific investigation" as actually "doing a scientific investigation." That is, what scientists *do* as a scientific inquiry is an authentic scientific investigation. This is different from what students do as scientific experiments in conventional science education classes: "Learning about scientific investigation." This is not to underestimate the value of learning about scientific inquiry; rather, it helps differentiate the two essential components of science education: (a) getting ready to do science, and (b) doing science.

In conventional K-12 science education, designed curricula aim to teach students about the methods and knowledge of science. Generally in K-12 and often in higher education, students in science classes learn how to find the correct answers to scientific problems, how to accurately explain physical phenomena, or how to precisely apply predetermined science formulas and equations. The scientific experiments that students conduct are often replications of previously completed investigations. A common characteristic of these experiments is that there is always an authority (a teacher or a textbook) who can judge the correctness or the accuracy of students' conclusions or their scientific findings.

Most standardized tests and even open-ended type science exams encourage students to learn about existing scientific methods and knowledge. Students acquire knowledge so that they can choose the correct answer among given alternatives or provide a plausible explanation of a given phenomenon. Students' performances are measured by the extent to which their responses or the explanations are in line with the scientific texts. Mostly because of the institutionalized nature of the school system (Pinar et al., 1995) and partly because of the standardized tests (Blades, 1997), at schools, students are always encouraged to learn the accurate descriptions of physical phenomena in accordance with the current scientific paradigm. In these practices, students learn about an end product of science: The scientific knowledge that is found in texts.

Kuhn (1962) pointed out that school science is persuasive and pedagogical. What students learn in conventional school science is an end product of scientific practice. I recognize the importance of familiarity with scientific texts; nevertheless, I contend that this is different from doing science. In that regard, learning about scientific methods and established knowledge is a means of getting ready to do science. Yet, getting ready to do science is not doing science, and therefore these practices do not encompass authentic scientific investigations.

I view doing science as the act of making judgments, drawing conclusions, or analyzing relationships regarding physical phenomena through the use of methods and knowledge accepted by the scientific community. In that regard, getting ready to do science is learning about judgments, conclusions, and relationships already documented in written texts. Kuhn maintained that it is important for a scientist to be familiar with scientific texts since the knowledge and methods found in scientific texts are direct references to the tools and techniques necessary for accomplishing any scientific task. Therefore, getting ready to do science is a necessary condition for doing science; however, it is not doing science, that is conducting authentic scientific investigations.

A distinctive characteristic of authentic scientific investigation is that the results are unknown. With respect to school science, an authority (a teacher and/or a textbook) usually knows the results prior to students' scientific investigations. This knowledge or the power to speculate on the findings precludes authentic scientific investigation. Regardless of whether an instructor's strategy is innovative, if the instructor knows the results before the students, then the students' practices become "un-authentic" and they differ from formal science practice.

In literature on science education, one finds several definition of "authentic scientific investigations." At the simplest level, an authentic scientific investigation is the adaptation of formal scientific inquiry to science education (Brown, Collins, & Duiguid, 1989; Edelson, 1998). However, adapting formal scientific inquiry does not simply mean students are replicating previously completed scientific experiments. Thus differentiating the practices of doing science and getting ready to do science is important when addressing the characteristics of “authentic scientific investigations.”

Hodson (1998) also made a distinction between getting ready to do science and doing science. In his book entitled “Teaching and Learning Science: Toward a Personalized Approach,” Hodson created a theoretical framework for achieving scientific literacy for *all*. He categorized the three components of science education as (a) learning science, (b) learning about science, and (c) doing science. According to Hodson, learning science is acquiring the theoretical and the conceptual knowledge of science that can be found in texts. Learning about science is developing an understanding of the nature and methods of science and an awareness of the relationships among science, technology, and society. Doing science, on the other hand, is engaging in and developing expertise of (authentic) scientific inquiry. Hodson, in his description of “doing science,” highlighted the importance of authentic scientific investigation and he differentiated it from “learning science” and “learning about science.” I make a similar distinction; however, in my conceptualization, getting ready to do science encompasses “learning science” and “learning about science.”

Authentic scientific investigations (or doing science) have particular characteristics that are different from merely acquiring scientific knowledge (or getting ready to do science). Edelson (1998) listed three characteristics of authentic scientific investigations: (a) attitudes, (b) tool and techniques, and (c) social interaction. He stated:

> It is seductively easy to focus on scientific knowledge, tool, and techniques at the expense of other elements of scientific practice. However, scientists' attitudes and their social interactions are also defining features of scientific practice. For students, understanding these attitudes and interactions is essential in order to understand the scientific process and to interpret the products of science. The key features of scientific practice fall into three categories: attitudes, tools and techniques, and social interactions. (Edelson, p.318)

According to Edelson, scientific practice requires *uncertainty* and *commitment.* He argues that an authentic scientific investigation must encourage students to be *uncertain* about the processes and the results of their investigations, as are scientists. That is, students must have the opportunity to adopt questions that represent true uncertainty in their world. Edelson contended that students should be comfortable with the idea that their investigation is open-ended. This requires students to be aware that both the techniques and the results of their investigations are subject to change and continual re-examination. I further contend that teachers should also be aware of and comfortable with this *uncertainty* condition for their students' scientific investigations. Being *uncertain* about the results is often an unfamiliar attitude especially for the students who are used to check their conclusions with their teachers or with a textbook.

Commitment to their practices is another important attitude of scientists that should be required of students "doing science." Edelson (1998) pointed out that scientists pursue issues for a variety of reasons. But whatever their interest, they commit themselves to findings answers to the questions they identify. Therefore, students "doing science" should also commit themselves to their investigations. One way to encourage students to commit to their investigations is to let them decide what to investigate, thereby giving them ownership of their work. Edelson maintained that in order "to foster commitment among students, the questions they pursue must have ramifications that are meaningful within the value system of these students" (Edelson, 1998, p.319). If they are allowed flexibility in their investigations, they will more likely to find connections between their value systems and the results of their investigations. I further argue that students will be more likely to commit themselves to their investigations if they believe that their work will generate new information or an original conclusion. In other words, students' investigations should have the potential to come up with something that is neither known by their teacher nor reported in textbooks.

Another component of authentic scientific investigations, according to Edelson (1998), relates to the tools and techniques that are shared across a community of scientists. The tools and techniques establish a shared context that facilitates communication within the community (Edelson, 1998; Edelson & Gordin, 1998). These tools and techniques include, but are not limited to, the knowledge and methods shared by the scientific community (e.g., scientific facts, theories, and claims, modeling, scientific visualization, etc.) and the medium and context of communication (e.g., language, written text, technological tools, the Internet, etc.). Students need to use these tools and techniques not only to conduct their investigations but also to communicate with each other and establish a community. Edelson noted that it is relatively easy to focus on tools and techniques in designing science learning environments; however, they are not sufficient for creating an authentic scientific investigation context.

The third component Edelson (1998) identified is that of social interaction. Social interaction includes, but is not limited to, the sharing of results, concerns, and questions among a community of scientists. According to Edelson, this social interaction has the same characteristics of co-operation and competition, agreement and argumentation that accompany all human social activity. The key component of the social interaction is that scientists continue to enact their practices through their interactions. A scientist does not end her product and then interact with the other scientists; indeed, she interacts with the other members of the scientific community in all phases of her practice, including the questions posed, methods followed, conclusions derived, and knowledge legitimized.

Edelson (1998) suggested that “a successful adaptation of scientific practice for learning will place the tools and techniques of scientists into the hands of students in a context that reflects the characteristics of science practices” (p. 319). For a successful adaptation of scientific practice, students should conduct open-ended investigations that they are genuinely concerned about, using methods parallel to those of scientists. Through this process, students engage in active interchange with others who share their interest. This collective interest, the commitment to their practices, and uncertainty of their investigations are the sine quo nons of authentic scientific investigation contexts.

Social interaction among students is important to a successful adaptation of formal scientific practice because it differentiates knowledge generation from knowledge transmission. In traditional laboratory practices, the overall aim is to transmit scientific knowledge to students by asking them to replicate already judged scientific investigations. In formal science, scientists aim to generate knowledge using previously judged scientific information. The methods and knowledge found in texts are used for utilitarian purposes and as a means to communicate, but not for legitimizing the investigation results. Social interaction plays a main role in decisions to accept or reject investigation results that are not described in scientific texts. In contrast, students in traditional laboratory sessions refer to the scientific texts to judge their results and to legitimize their conclusions. They do not need social interaction to decide the validity of their findings or scientific conclusions. In that sense, traditional laboratory activities that replicate scientific texts become persuasive and pedagogical. Students use scientific knowledge that scientists use but they do not have the opportunity to experience scientists' social engagement and feelings of commitment. According to Edelson (1998), even though traditional laboratory activities are intended to give students the opportunity to employ authentic scientific tools and techniques, because the design of laboratory experiments usually removes any uncertainty, there is little opportunity to feel commitment, and to engage in social interaction.

In summary, an authentic scientific investigation should include not only the tools and techniques the scientific community utilizes, but also the attitudes of uncertainty, commitment, and social interaction. A means of generating uncertainty and student commitment is to begin with questions that are open-ended. This open-endedness ensures that neither the teacher nor the textbook provides clues to the results prior to students' practices. Social interaction among students can replace the role of the instructor or the authority of the textbook in deciding the validity of students' investigation results.

3.3 College Peer Review (CPR) Project

The CPR project, in which a contextual and implicit NOS instructional strategy is implemented, has a design based on the sociological NOS. The sociological NOS was embedded within the activities of the project: original research, on-line collaboration, and peer review.

The CPR project is a multi-university project that has been implemented every academic semester since Fall 2001 (Trautmann, Carlsen, Yalvac, Cakir, & Kohl, 2003). The number of students participating in the project during the two investigation phases of this study are listed in Appendix G and Appendix H. These lists also include the classes students enrolled in and the name of the institutions they belong to. The two investigation phases of this study were a pilot study and a research study. The context described here is based upon my observations from the pilot and the research studies implemented in Fall, 2001 and Fall, 2002 respectively. I observed a science education method course, SCIED 411, at Pennsylvania State University. The students of SCIED 411 classes have participated in the project every semester since Fall 2001. Dr. William S. Carlsen, the leader of the CPR project, taught these classes.

The original research aspect of the project covers a toxicology experiment that students conducted over a week-long period. The on-line collaboration aspect involves student information gathering and the communication stages. In the peer review, students review each other's reports and evaluate these works via the Internet. In the sections that follow, I describe these aspects through the steps taken by a student who participated in the CPR project.

3.3.1 Introduction of the CPR Project in Participating Classrooms.

In the early Fall semesters of the years 2001 and 2002, participating faculty (see Appendices G and H) described the project specifications to their students. The materials required for the toxicology experiment (Petri dishes, filter papers, seeds, etc.) were provided by either the institutions' lab resources or by mail from Pennsylvania State University. Faculty informed their students how to carry out a toxicology experiment. Course instructors distributed serial dilution, and lettuce seed dose/response bioassay protocols (Environmental Inquiry protocols) that were particularly designed to teach K-12 students how to conduct a bioassay (Trautman, Carlsen, Krasny, & Cunningham, 2001). A number of other Environmental Inquiry protocols can also be found in "Assessing Toxic Risk" (Trautman et al., 2001), published by the National Science Teachers Association Press. In the SCIED 411 class, instructor Dr. Carlsen asked students to read the protocols within a week and come with their questions, if any part of it was not clear to them. Students later expressed that they were familiar with the protocol procedures. Other participating faculty provided their own methods to ensure that their students were informed about the procedures of a bioassay. The entire participating faculty also provided their students with instructions for registering on the project web site: http://ei.ed.psu.edu/CPR/register/register.asp. CPR project leader Dr. Carlsen assisted the faculty, providing technical help on-line.

In the SCIED 411 class at Pennsylvania State University, students completed an on-line philosophy of science questionnaire on the first day of class. In the present study, SCIED 411 students' responses to the questionnaire were used for research purposes. Details about the questionnaire and the analysis of students' responses are presented in the next two chapters (Chapter 4, Methods of Inquiry and Chapter 5, Findings of the Study).

3.3.2 Original Research

In an authentic scientific investigation, as defined in this study, the information gathered at the end of the activity is open-ended and directed according to the interests of the participants. Neither the teachers nor another authority (such as a textbooks) know the results of the investigation beforehand. Hence, students are empowered to come up with the results and construct the knowledge they generate. This does not necessarily mean that students are expected to design an experiment from scratch. In fact, "starting from scratch" would probably not be an authentic investigation, because most experiments are based on earlier experiments.

In the CPR project, in order to engage students in an authentic scientific investigation, Environmental Inquiry bioassay protocols were used. Students were provided with structured bioassay protocols, in order to assess toxicity of a chemical that they were free to choose. Because students were choosing any chemicals, neither the teacher nor the student was familiar with the probable findings of the bioassays before the investigations were started. For example, a student reported that she had chosen toothpaste as a toxic chemical and assessed its toxicity on lettuce seeds. Students were also free to choose any organisms (any seeds) available in class during the investigations. In cases where students used the same chemicals, the organisms were chosen differently. Because there is an enormous amount of possible bioassay results, the findings of those investigations are open-ended.

The participants in the second phase of the study are some college students who were enrolled in the SCIED 411 Science Education Methods course at Pennsylvania State University in the Fall semester of 2002. The activities of the CPR project were completed by hundreds of students in several different institutions (see Appendices G and H). The classroom conditions and laboratory environments varied. The classroom context of the CPR project described here is based on practices done in the SCIED 411 course at Pennsylvania State University, which was one of the participating institutions among a dozen others.

Before starting their experiments, students in the SCIED 411 class, were informed about how to locate, read, and utilize a Material Safety Data Sheet (MSDS) of a substance. An MSDS of a particular substance provides information on how to properly handle and work with that substance. MSDS includes useful information about the substance, such as physical data (its boiling point, melting point, flash point, etc.), toxicity, health effects, first aid, reactivity, storage, disposal, protective equipment, and spill/leak procedures. Because students were expected to work with substances that might be hazardous to environment, as well as to themselves, informing students how to locate, learn, and utilize the MSDS was important.

Students in the SCIED 411 class conducted experiments in groups of two. They followed the steps suggested by the Environmental Inquiry bioassay protocols (Trautman et al., 2001). After a group of students had decided on a chemical they wanted to use in their bioassays, they prepared a series of solutions, each ten times more diluted than the one that it was made from (6 dilution with concentrations ranging from 100 to 0.001 percentages). Each group prepared twenty-one 100 mm petri dishes with filter papers placed in them. Three of these petri dishes were used as a control group and labeled. In each of the control dishes, 2 ml of diluted water was dropped on the filter papers and five seeds were set on the paper. The other eighteen dishes were divided into six treatments, each constituting three dishes. In each dish, 2 ml of the appropriate concentration was added, along with five seeds. Overall, there were six experimental treatments and one control dish treatment. Students closed all the petri dishes and placed them in a plastic bag to retain moisture. Students also covered the bags with aluminum foil to exclude light.

After five days, students opened the petri dishes. They counted and recorded the number of the germinated seeds in the petri dishes. Student pairs also measured the radicle length of each germinated seed (the embryonic root). In the Environmental Inquiry protocols, the directions for measuring the embryonic root was explained, but the authors of the protocol intentionally left somewhat ambiguous how to determine precisely where the radicle begins. I observed that some students were uncertain how to measure the radicle lengths, because where the root started on the seed was not always clear. Students were not sure where the root was started and from where they should take their measurements. After some discussions among groups, most of the students reached agreement on a particular convention and measured the other root lengths in reference to that particular part. It was left to students to decide whether or not to measure ungerminated seeds length as “zero” and record it in their data pool. This part was deliberately left ambiguous to students. Students recorded their data and drew two graphs (average number of seeds germinated versus concentration, and average radicle length versus concentration). Following written instructions, the students determined the TC50 (the toxic concentration of a chemical that causes organisms to grow 50% as well as the control group) of the chemical they had chosen to assess. After students completed the bioassay, they worked individually to write a report on their findings.

3.3.3 On-line (and other) Collaborations

Students collaborated at different stages of the project. Project-wide, most students conducted their experiments in groups of two to four. In the SCIED 411 course, at Pennsylvania State University, students worked with one partner. Students in groups of two collaborated in deciding on the chemical they wanted to use, completing the protocol procedures, and collecting the data. Students wrote their reports individually.

While students were measuring the radicle lengths, it was necessary for them to collaborate within and between groups. Kuhn (1982) asserted that the meaning of scientific measurement is never completely objective. Students in a group were forced to decide together how to measure the radicle length of a germinated seed. Where the radicle of a seed started was not clearly visible and there was no evidently objective way of measuring the radicle length. Therefore, the students worked with their partner to establish a particular visual convention, and they measured the radicle lengths of other seeds in reference to that particular part on each germinated seed.

In some instances of the SCIED 411 class, students in different groups also collaborated. In the beginning of the bioassays, two to three groups of students came together and decided to assess the toxicity of chemicals related to each other. For example, three groups decided to conduct three different bioassays to assess the toxicity of a solute, its solvent, and an equal combination of these two. The solute was a chemical sprayed on the tops of greenhouses to protect plants from extra radiation in the summer. Its solvent was another chemical agent sprayed on the top covers to rinse off the solute away in the winter. The students acquired Materials Safety Data Sheets (MSDS) from the European manufacturer, and noted that the solute and solvent toxicities had been separately investigated. The combination of the solute and solvent was considered a potentially toxic chemical that could be found in the soil next to a greenhouse. The three groups of students collaborated with each other to assess the toxicity of the chemicals independently and together. In that manner, students communicated within and across groups, and all together decided to choose the chemicals on which they wanted to run a bioassay.

In terms of on-line collaboration, peer review was the major activity. In peer review, students reviewed each others' on-line reports. Reviewers provided feedback to help authors to improve the quality of their reports. I consider this communication and decision-making process as the basic collaborative aspect of the project. On-line peer review was not something with which many students had previous experience. It had the potential to represent how the sociological NOS was embedded in scientific practice. Through peer review, students had the opportunity to communicate about their investigation methods and scientific results. The hope was that students would learn from each other's research experiences, scientific conclusions, and also reviews of others.

Students were also provided with the on-line reports published in previous years. If students had wanted to review similar research findings, they had the option to read those reports on-line. In this study, I did not investigate participants' communications with students from previous years; however, a few students told me that they read some of the reports posted previously.

3.3.4 Peer Review

Peer review is an important aspect of the scientific knowledge generation process in modern societies (Bakanic, McPhail, & Simon, 1987; Ziman, 1980). Even though it has not always been called peer review, academics in educational institutions have been reviewing one another's work for the last three centuries (Roy, 1985).

After students collected data in their toxicology experiments, they were given two weeks to post their findings anonymously as on-line reports on the project website. Meanwhile, they were assigned to review two other posted reports, also anonymously, using a web-based form (Appendix D). Several days after a student posted her report, she would log on to the website and access two reviews of her work. Because reviewers did not know who the authors were and authors did not know who the reviewers were, the peer review system can be considered double-blind. Reviews occurred across institutions randomly (for the list of the participating institutions, see Appendices G and H). Reviewer were randomly assigned to review report written by authors across the institutions. Therefore, it was a probability for a student to review a report written by someone from her class or someone from a class in a different institution. This brings a possibility that partners might have reviewed each other's reports, that would not be an ideal case. In the SCIED 411 class, none of the student groups of two reported that they reviewed their partner's report in the on-line peer review. If this was the case, reviewers would be asked to review another report other than their partners.

Students were asked to revisit their reports considering the recommendations to their original reports. They either changed some parts of their reports or did not change them at all. They were free to choose. As a final step in peer review, students "published" their final reports. They could elect to publish their final reports anonymously or with their name and institutional affiliation attached. It was expected that the students would self-attribute their reports, because this feature is analogous to the publication of a scientific report in a journal. As a general tendency, more than half of the students posted their final reports with their names.

Students who voluntarily participated in the social science research aspects of the project were directed to a web page including a demographic and a final questionnaire. Within the SCIED 411 group, students were also asked to complete the on-line philosophy of science questionnaire a second time.

3.3.5 Authentic Scientific Investigation and the CPR Project

In this section, I revisit the features of an “authentic scientific investigation” and explain how the CPR project encompasses authentic characteristics of scientific practice.

In the CPR project, students were engaged in open-ended scientific investigations (original research) fulfilling the characteristics of authentic scientific practice (Trautmann, Carlsen, Krasny, & Cunningham, 2001). Participating students used the tools and techniques necessary to accomplish their investigations. Students were provided with the methods and knowledge of science to conduct a toxicology experiment. The materials required for the experiment (e.g., the chemicals, the organisms, Petri dishes), measurement strategies and observation tools (e.g., counting the number of germinated seeds, measuring the root length in mm), relevant graphs and representations (e.g., x-y coordinate system, tables) and the technology needed for communication (e.g., the peer review system, the Internet) were all provided.

Students chose the organisms they wanted to work on, and the instructor guided them based on students' decisions. Students' investigations were open-ended. Even though it was not the focus of this study, participants reported their commitment to their investigations; in the post-interviews students said they were eager to conduct their experiments and were enthusiastic about knowing their results (for details refer Chapter 5). The uncertainty of students' investigations was thoroughly achieved in the original research aspect of the project. This uncertainty might have influenced students' commitment to their investigations.

The social interaction emerged through students' group work and in their reviews of one another's reports. The crucial aspect of this social interaction was that it did not happen after students finalized their investigation and reported their final results; rather it happened as they were generating their conclusions. After social interaction, students had the opportunity to revisit their conclusions and revise them based on the information generated through the social interaction. The social interaction empowered students to decide on the appropriateness or the accuracy of one another's investigation methods and findings.

Because of the characteristics listed above, the context of the CPR project was an authentic scientific investigation.

3.3.6 Consent Forms and Other Issues

When students first registered on the website, they were directed to a project description. In this description, students were asked to complete an on-line consent form, represented in Appendix I. All the students were required to complete the activities of the CPR project. However, it was optional for them to participate in the research aspects of the project. If a student had chosen not to participate in the research, she was assigned a user account, but she was not directed to a demographic information web page and was not asked to complete a final questionnaire. It was clearly stated that students' grades would not be affected by their willingness to participate in the research aspects. If students chose to participate in the research, they were asked to complete a demographic questionnaire (Appendix E), and a final questionnaire (Appendix F). Demographic information and other information provided on-line were accessible to course instructors and researchers of the project. In this study, because of the research design and the in-depth analyses it required, I used only the information relevant to students at Pennsylvania State University. In other aspects of the CPR project research, other researchers used information from other samples.

3.4 Peer Review in Science

Peer review, the core idea of the CPR project, is commonly used in generating and validating scientific knowledge, claims, and facts in science (Roy, 1985; Bakanic et al., 1987). However, peer review as it is used in science is not a perfect system (Nash, 1996; Ziman, 1983). Therefore, I include another section that addresses what peer review is and the criticism of it.

Oxford English Dictionary (2003) defines the word “peer” in English as “an equal in civil standing or rank; one’s equal before law,” as dated in 1215. Since then, the word “peer” has commonly been used as a noun indicating a group of people who are equal in any respect.

The word “peer review” is not cited until 1971. The three definitions of “peer review” given by the Oxford English dictionary (2003) are as follows:

1. The evaluation, by experts, in a relevant field, of a scientific research project for which a grant is sought (used first in 1971).
2. The process by which a respected journal passes a paper received for publication to outside experts for their comments on its suitability and worth; refereeing (used first in 1975).
3. An examination or review of commercial, professional, or academic efficiency, competence, etc., by others in the same occupation (used first in 1979).

“Peer review” within a scientific community has been in existence under that label for only two decades. It has two common meanings (Bakanic et al., 1987). First, it is a decision-making process, in which government agencies ask some qualified individuals to review proposed research, and then use this information to decide on whether to fund the research. Second, it is a process in which qualified individuals (peers) review the reports written by researchers. The aim of the reviews is to evaluate the information presented in the reports in order to decide on whether it is worthy of being published in an academic journal. In a broader sense, peer review is a qualitative judgment about the scientific value and publication relevance of a piece of writing.

3.4.1 Critics of Peer Review

Peer review stems from the idea that reviewers will objectively evaluate either a research proposal or a report of a completed investigation based upon the originality of the ideas represented. Whether it is a proposal or completed research, peer review directs the scientific enterprise; which step will be taken next or what information will be legitimized. Reviewers play a significant role in the decision-making process of a review and the knowledge it generated (Bakanic et al., 1987; Nash, 1996; Roy, 1985; Travis & Collins, 1991).

According to Nash (1996), peer review does not simply help determine if work will be published and where. Indeed, it is the supreme organizing principle and condition of the world of science. Nash's (1996) criticism is that a reader or a reviewer does not see the stages of selection and the judgments involved in determining if an article is to be published. The reader only sees a publication, a judgment delivered. Some undesired and inconvenient parameters (biases) may play a role in that judgment, though they may be easily hidden in the selection stages of a publication. These parameters as biases of peer review are scrutinized under the titles of originality, particularism, and collectivization of science (Carrol, 1990; Travis & Collins, 1991; Ziman, 1983).

Originality is defined as "the quality of being independent of and different from anything that has appeared before; novelty or freshness of style and character" (Oxford

English Dictionary, 2003). Originality in science refers to the quality of the ideas as being primary or first-hand. The originality of scientific claims is gauged by the degree of independence in originating new or fresh ideas or methods. In scientific enterprise, the originality of ideas is a major parameter that is used to validate the proposed ideas (described by a research proposal or a completed investigation).

Carrol (1990) asserted that the concept of "originality" in academia is used to justify and rationalize a class system based upon claims of property in ideas. According to Carrol (1990), that kind of class system, which is legitimized by the originality of ideas, preserves hegemony among a group of males in order that they control the received knowledge and a variety of rewards and privileges. A lack of "originality" is commonly projected to the works of women, causing them to be excluded from academia as intellectuals and scholars.

Spainer (1995), in her book entitled "Im/partial Science; Gender Ideology in Molecular Biology," provides evidence that the works of women intellectuals have often been rejected in scientific peer review because of a supposed lack of originality in the scientific claims. For instance, in biological sciences, scientific research findings aligned with a feminist perspective can easily be found "less legitimate and less objective" compared to the works of other scientists who are published. Spainer states:

> Feminist perspectives are often charged with being biased, because they are overtly political and come from a set of defined interest. What is ignored is that everyone has a set of interest, but they are not usually acknowledged, particularly in the sciences, where a cult of objectivity both denies and obscures social, cultural, and economic influences. (Spainer, 1995, p.75)

Longino (1990) explored how social and contextual values play a role in science. Science is value-laden, and scientific claims, which are purported to be objective, include human values and presumptions. Longino explained that “good science” practiced by the dominant group of people also has human values. In that sense, a measure for originality of ideas is not equally operated to the works of all scientists proposing scientific claims based upon their schools of thought. Nevertheless, feminist intellectuals may be excluded from the academia for being unoriginal, even though it is impossible to achieve originality that encompasses no human values.

Carrol (1990) suggests that it is essential to understand originality in academia and alternative conceptions of creativity and value in works of art, science, and intellects. This is important to promoting “scientific literacy for all” and investigating why minorities are excluded from the scientific enterprise.

In the present study, I did not investigate the issue of exclusion of women from academia or misrepresentations of their intellectual contributions. This is one of the limitations of this study, and I propose such an investigation for the future studies.

Generalizibility and objectivity are the two commanders of science aligned with logical positivism and realism. Particularism refers to reviewers’ attitudes and their decision-making process that prevents the generalizibility and objectivity of scientific practice. “Old boyism,” a traditional term, or “cronyism,” its sex-neutral alternative, describes reviewers’ favorable decision-making based upon factors that are not consistent with the generalizibility and objectivity of scientific practice. It has to do with sharing similar institutional quality and/or sex.

Travis and Collin (1991) coined the terms cognitive particularism or cognitive cronyism to describe a bias in peer review that is not based on sex or institutional biases but on a school of thought. They claimed that cognitive particularism tends to favor research proposals written by the members of same school of thought.

Travis and Collins (1991) scrutinized peer review practiced in the United States and in Britain. The U.S. National Science Foundation (NSF) makes use of a system of expert reviewers, sometimes in face-to-face meetings, and sometimes via mail or secure web reviewing system. In Britain, a similar system called Science and Engineering Resource Council (SERC) makes use of a system of postal references. A difference of SERC compared to NSF is that, in SERC after the reviews are completed, the comments and the scores are considered by a dozen members whereas in NSF, comments and scores directly influence the decision of the reviews. In other words, the SERC officials on subject committees have no decision-making authority whereas NSF members do.

Travis and Collins (1991) argue that the existence of bias in a peer review system is based on a limited and partial view of science. Their observations revealed that committee members often made decisions based upon their membership in scientific schools of thought. The reviewers favored the publications relevant to their school of thoughts and which had similar conceptual frameworks. That pattern was more visible in NSF reviews than in SERC reviews.

Because of reviewers', limited or particular views of science, funding for the most innovative scientific investigations may be rejected. Travis and Collins (1991) found that committee members in Great Britain often made decisions based upon their membership in scientific schools of thought. This bias was more serious in the NSF process, because reviewers' comments were used in the decision-making process.

A friend of mine, who is working on his PhD in the field of Bioengineering, told me about an experience he had related to peer review. His advisor was a well known and respected professor in his field of study. My friend's advisor told him that NSF was offering him grants even though he had not submitted reviews or a proposal. My friend defended this practice, arguing that his advisor had proven himself and deserved to receive grants even without a proposal. This conversation revealed to me that the peer review system as it is practiced in our academic institutions can sometimes have more to do with social networks than with objectivity and fairness. I was particularly concerned about grants that never become available because the funding was already and unfairly distributed to some "overqualified" researchers in the fields.

I have experienced many times that science students in general perceive science as an individual practice--a way of knowing the world that one can practice anywhere under any conditions. This belief about science is called the individualism of science. It has roots in logical positivist and realist perspectives of science.

Ziman (1983), in one of his lectures, spoke about J.D. Bernal's radical commentary on 'the social function of science' that had become the conventional wisdom of public science policy. Public science policy requires science to be organized and financed on a large scale, and directed toward societal goals. Ziman (1983) stated that science has been <u>collectivized,</u> arguing that the traditional individualism of the academic mode of research has been decisively and irreversibly curbed. Crucial decisions in the research process now may rest in the hands of organized groups of people, and not independent scientists (Ziman, 1983). The members of a peer review system effectively decide which questions are to be studied by which method. It used to be that individual scientist were more to decide by herself the choice of research problems. However, that freedom has been severely curtailed. Ziman (1983) commented that “the resources for research in a particular field are only made available for projects that are specifically approved by the grant-awarding bodies in that field.” If you are a competent scientist and formulate a scientific problem that you find interesting and valuable to study, you may never find the means to do research on this problem unless it corresponds to some governmental or financial interest.

Chapter 4

Methods of Inquiry

4.1 Overview

In the sections that follow, I describe the methods of inquiry that informed the research design, the data collection, and the analysis. This study utilized a collective case study design (Merriam, 1998; Stakes, 2000; Yin, 1994). The primary data were collected through interviewing and analyzed utilizing the constant comparative method (Glaser & Strauss, 1967).

The present inquiry is a qualitative study. Qualitative research methods are based on the assumption that “reality is constructed by individuals interacting with their social worlds” (Merriam, 1998, p.6). In qualitative research, the researcher’s role is to capture the meaning that people have constructed through their experiences in the world. The researcher is the primary tool of data collection and its interpretation, and the researchers’ beliefs about reality and the nature of knowledge influence the study methods and the knowledge generated (Baptiste, 2001). I play a role in constructing the knowledge represented in this study. Therefore, in order to assist the reader in making decisions about this study, I have included a subsection describing my background, personal biases, and beliefs.

4.2 Design: Case Study

Case study design is a term used in almost every professional field (Merriam, 1998; Stake, 2000). In the science education field, I found Merriam's (1998), Yin's (1994), and Stake's (2000) descriptions most useful. I explain the design of the present study in reference to these three researchers' work.

4.2.1 "Case" Under Investigation

Stake (2000) pointed out that "case study is not a methodological choice but a choice of what is to be studied" (p.435). Case study approaches may be best described by researchers' interest in individual cases rather than in the methods of inquiry used (Merriam, 1998; Stake, 2000). In this study, my aim is to illuminate college students' NOS understanding in general, and their sociological NOS understanding in particular, in relation to their participation with the CPR project activities. Because my interest is students' NOS understandings, in the present study, a "case" under investigation is "a college student who participated in the CPR project and her conceptual ecology."

4.2.2 Significance of Case Study in Social Research

Yin (1994, p.13) defines the scope of a case study as "an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident." This definition emphasizes the selection of a case study design in social research when the boundaries between the phenomenon and the context are blurred.

In this study, the phenomenon under investigation is students' understanding of the NOS. The context is students' participation with the activities of the CPR project. The activities of the CPR project were purposively designed in order to model for students how scientific claims are generated in a scientific community. This demonstration was achieved through students' active participation with original research, on-line collaboration, and peer review. The instructional strategy used in the CPR project is implicit and contextualized, as discussed in Chapter 3. In summary, the tenets of the NOS were not made explicit throughout the instruction, but rather left to participants to conceptualize. Because of the nature of the instructional strategy used in the project, there was no one-to-one correspondence between the tenets of the NOS intended by the project and post-understanding of the NOS students conceptualized. Moreover, there was not a clear cut prediction of the NOS that students should grasp after the project was ended. Students' post-understanding of the NOS was open-ended. The boundaries between the intention of the project and the students' post-conceptions of the NOS were blurred. It was not clearly evident in advance which ways and to what extent the context of this study (students' participations with the activities of CPR project) would influence the phenomenon under study (students' understanding of the NOS). Therefore, a qualitative case study design described by Merriam (1998), Yin (1994), and Stake (2000) best fits this type of investigation.

4.2.3 The Design of the Study: A Collective Case Study

Stakes (2000) identifies three types of case study designs according to the goals of the research inquiry and the number of case(s) used.

When the primary research interest is in the case itself, Stake (2000) calls that kind of study an intrinsic case study. In an intrinsic case study design, the researcher "wants better understanding of a particular case" (Stake, 2000, p. 437). The case is often an individual or a program and on occasion a phenomenon. The case is not chosen because it represents other cases or provides insight into some other phenomena. It is chosen because the case itself is of interest. The purpose of an intrinsic case study is not to build a theory or to generalize findings. An intrinsic interest in the case itself initiates the inquiry and so the purpose of the research. For example, an autobiography written by Kinross (1964) about Ataturk illustrates an intrinsic case study.

When a researcher's interest in a case includes an intention that the case will tell about a broader class of cases, Stake (2000) calls that kind of study an instrumental case study. In an instrumental case study, a case is examined because the goal of inquiry is to provide insight into an issue or to draw a generalization. In instrumental case studies, the case is of secondary interest: the researcher has other interests beyond the case itself. The cases help to provide a better understanding of something else. Stake (2000) mentions that in instrumental case studies, the case is still looked at in-depth with a thorough description of its context, similar to an intrinsic case study design. However, the investigation primarily serves an external interest.

When an instrumental study is extended to multiple cases, Stake (2000) calls it a collective case study. The cases in a collective case study design are chosen because "it is believed that understanding them will lead to better understanding, perhaps better theorizing, about a still larger collection of cases" (Stake, 2000, p.437). Therefore, a collective case study has a secondary interest plus an in-depth investigation of each case studied. It is an interpretive study in its nature "with less emphasis on a single case" (Stake, 2000, p.437).

The design of the present study is a collective case study. In other words, it is a multiple-case, instrumental design. In the present design, I worked with five participants who were purposively chosen (Patton, 1990). Each of these participants and their conceptual ecology represents a different *case* and can be separately investigated. These five cases are of "secondary" interest; even though in-depth investigation for each case was performed, the primary interest is to learn from these cases and generalize the findings to other college students who participated in similar activities like the CPR project.

Merriam (1998) advises researchers to define the boundaries of the cases under investigation. The purpose of this study is to explore the ways in which and the extent to which college students' conceptions of the sociological NOS change within the context of the CPR project. College students who participated in the CPR project constitute a group of people. This group of people all participated in the activities of the CPR project and were all college students who enrolled in either a science education course or a science course. Therefore, the boundaries (Merriam, 1998) in this study are experiences with the CPR project, being enrolled in a science or education course, and conceptualizations of the NOS.

Merriam describes the case study in reference to its special features (Merriam, 1988, p. 11). After reviewing literature including Guba and Lincoln (1981), Helmstadler (1970), Stake (1981) and Wilson (1979), Merriam (1998) suggests that there are four features that are essential to a case study. These features are: (a) Particularistic, (b) Descriptive, (c) Heuristic, and (d) Inductive.

The particularistic feature of the case study is that the object of study is a particular situation, event, program, or phenomenon. "The case itself is important for what it reveals about the phenomenon and for what it might represent" (Merriam, 1988, p. 11). Five college students' understanding of the NOS are the objects of this study that changes in their conceptions of the NOS provide insights about the influence of the CPR project.

The descriptive characteristic of a case study concerns the end product of research. A case study is one with a thick description of the phenomenon under study (Merriam, 1998; Yin, 1994). In the present investigation, the phenomenon I study is how college students' conceptions of the NOS change. To elucidate changes in participants' conceptions of the NOS, I thoroughly describe students' understanding by providing illustrative excerpts from the interviews and students' written responses. These descriptions, all of which are qualitative, include but are not limited to evidence of participants' pre-conceptions and post-conceptions of the NOS derived from interviews, questionnaires, and other written works.

The heuristic feature of a case study is that it "illuminates the readers' understanding of the phenomenon under study" (Merriam, 1988, p.13) by generating new questions. Students' sociological NOS conceptions are rarely addressed in the science education literature. The present study draws attention to students' sociological NOS conceptions (in Chapter 2), in addition to how the CPR project plays a role in students' understanding of that kind (in Chapters 3, 5, and 6). The findings of this study may inspire readers to focus on the social constructivist and relativist orientations of science in teaching the NOS tenets. Readers may pose new questions regarding students' understanding of science and the establishment of scientific knowledge that go beyond philosophical and sociological questions (as discussed in Chapter 6).

The inductive characteristic of the case study is that the method of investigation relies on inductive reasoning: "generalizations, concepts, or hypothesis emerge from an examination of data" (Merriam, 1988, p.13). In the present study, students' pre, post, and change in conceptions were categorized according to the codes that emerged through the analysis of data. I attempted to derive students' understanding inductively; however, I cannot claim that all the categorizations I made were completely inductive. There were some categories that I had predetermined, and I searched for similar incidents matching with these categories. There were also some categories that emerged during the analysis. Inductive reasoning was also used to compare changes in participants' views of the NOS.

4.2.4 Components of Case Study Design

In this section, I address the research questions, propositions, and the unit of analysis by explaining the relationships among them. The explanations of these components provide a framework for how participants were selected and how data were analyzed.

Yin (1994, p.20) identifies five components of a research design as significant. These components are (a) a study's questions, (b) its propositions, (c) its units of analysis, (d) the logic of linking data to propositions, and (e) the criteria for interpreting the findings.

The research question of a study provides an important clue for the research strategy used. According to Yin (1994), "how" and "why" questions are appropriate in a case study design. In the present study, the research question was stated as, "In what ways and to what extent are college students' conceptions of the sociological NOS influenced by their participation with the activities of the CPR project?" Even though this research question does not start with a "how" or "why" question, the analysis was derived from the answers of that type. How students' conceptions of the NOS changed (in the sense developed) and why these conceptions changed (is it because of their participation in the project?) are the questions that I sought answers for.

A study's proposition is that which the researcher intends to examine within the scope of the study. 'How' and 'why' questions do not address the matter of what the researcher should study. Therefore it is suggested that the researcher should state some propositions "to move in the right direction" (Yin, 1994, p.21). In this study, a proposition I utilized in data collection and analysis is: "generation of scientific knowledge requires social interaction, in addition to experimenting again and again." Under the guidance of this proposition, through my analysis, I was able to focus on students' understanding of the NOS or their lack of understanding. Another proposition of this study is that "good science strives to be objective even though it can never completely be objective." These propositions guided me both in data collection and in analyses.

However, it is essential to mention here that I was not aware of the study propositions when I first designed the pilot study for this research. After the pilot study, the research propositions started to become clear. In the second round of the study, I was able to focus on the dimensions of these propositions.

Specification of units of analysis is helpful to define what the case under investigation is. A clear definition of unit of analysis determines the limits of data collection and analysis (Yin, 1994, p. 25). The classic case study examines one case (Yin, 1994, p. 21). Case studies also can be some event or entity that is less well defined than a single individual. In this respect, the unit of analysis can be one individual or a group of individuals. Yin points out that if the unit of analysis is a small group, the persons to be included within the group must be distinguished from those who are outside of it. The group of people I was interested in studying is college students who participated in the activities of the CPR project. The unit of analysis of the present study is five of these college students.

Yin (1994) mentions that "linking data to propositions" and "criteria for interpreting the findings" have been the least well developed aspects of case studies. Case study design does not thoroughly address these components. Therefore, in this study the process of linking data to propositions and the criteria for interpreting the findings were achieved by employing the constant comparative method (Glaser & Strauss, 1967). I used the constant comparative method to analyze interviews in order to build a propositional theory but not a discussional theory (Glaser & Strauss, 1967). In discussional theory building strategy, the researcher discusses the conceptual categories and their properties, and the theory is represented in a running theoretical discussion. In propositional theory building strategy, the researcher presents a well-codified set of propositions that can be evaluated and tested in future research. Even though I often used discussional theory building strategy in explaining participants' understanding of the NOS, when I compared participants' changes in conceptions of the NOS, I used propositional theory building strategy. The methods of constructing the study propositions are discussed in section 4.9.

4.3 Participants of the Study

4.3.1 Overview

The study participants were chosen from a group of prospective science teachers who had been enrolled in a science education method course (SCIED 411) at Pennsylvania State University, University Campus, in the Fall Semester of 2002. Dr. William S. Carlsen, my dissertation advisor, taught the SCIED 411 course. I chose this class as the primary population for this research because it was accessible for me to communicate with the students and the instructor of the class regarding the research purpose.

Dr. Carlsen introduced me to the class at the beginning of the semester before the project was started. I had the opportunity to explain why I was interested in working with them. I told the class that I would select several of them and email an invitation asking them to participate in the study.

Students enrolled in the SCIED 411 course in the Fall Semester of 2002 had different backgrounds. Some of them already had their Bachelor of Science (BS) degrees. Students who had BS degrees were enrolled as graduate students and the others were enrolled as undergraduate students. Students enrolled in the SCIED 411 course were studying to be teachers of science.

4.3.2 Selection of the Participants of the Study

The participants of this study consisted of five college students selected purposively (Merriam, 1988). My research purpose was to explore in which ways and to what extent college students' conceptions of the NOS are influenced by their participation with the activities of the CPR project. I assumed that college students had some awareness of the NOS before they engaged in the activities of the CPR project. These preconceptions could range from simple to complex, and could be unique to that individual or shared by others. I did not want my interpretations to be affected by the uniqueness of my participants' pre-conceptions of the NOS. Therefore, I chose to study several participants, each of whom had a different pre-understanding of the NOS. It is essential to mention here that the range of this variance is unlimited when all college students are considered. In the present study, the primary population from which five participants were selected was 20 college students enrolled in a SCIED 411 course, during the Fall Semester of 2003. Hence, I considered a variance of preconceptions held by these 20 college students in the SCIED 411 class.

I used a maximum variation sampling strategy (Patton, 1990) to select five of the participants from the 20 college students enrolled in the SCIED 411 course. Maximum variation sampling involves purposefully picking a wide range of variation on dimensions of interest. This sampling strategy documents unique or diverse variations that have emerged in adapting to different conditions. It identifies important common patterns that cut across variations.

The major criterion for selecting participants of the study was their philosophies of science. I did not select participants who held similar philosophies of science because I did not want one unique pre-conception about science to hide probable influences of the CPR project. Participants' sexes and academic backgrounds were also considered as minor criteria in selecting participants.

I utilized an on-line philosophy of science questionnaire (Appendix A) to assess students' philosophies of science before the project was started. All the students enrolled in the SCIED 411 course completed the questionnaire in the beginning of the semester. The questionnaire was primarily designed to explore students' philosophies of science and science education (Lunetta & Crawford, 2001). Variants have been used in the Science Education program at Pennsylvania State University since 1999. The questionnaire consists of six questions, all of which are open-ended.

I analyzed students' responses to the questionnaire items in a way that was similar to how I analyzed the interview transcripts (as described in section 4.8), with fewer qualitative descriptions and more numeric categories. My analysis of the verbatim interview differed from my analysis of the students' responses to the questionnaire. My verbatim analysis was more descriptive and thick. In the questionnaire analysis, I did not write theoretical propositions regarding students' philosophies of science. I categorized students' responses according to how they perceive science and scientific knowledge. The categories I crafted from students' responses to the questionnaire items were "science is the study of nature," "science is progressive," "science searches for absolute truth," "science should be objective," "scientific knowledge is methodological and/or structured," "science is skeptical," and "science is logical". After I categorized these 20 students' responses regarding philosophies of science, I selected eight students so that their responses as a whole would include all the possible variations of the responses regarding philosophies of science. I selected eight students because I thought up to three of them might not be interested in participating. I contacted eight of these students via email and invited them to participate. Five of these eight students agreed to participate. A categorization of these five students' responses to the philosophy of science questionnaire items are listed in Table 4.1.

Table **4.1**: A Summary of Five Participants' Responses to the Philosophy of Science Questionnaire prior to the Project

Number of participants and the philosophies held.	**Participants (cases)**
2 of them responded that science is the study of nature.	Frank and Cindy
2 of them responded that science is progressive.	Liz and Megan
1 of them mentioned that science searches for absolute truth.	Liz
2 of them responded that science is/should be objective.	Jacob and Liz
3 of them responded that science is methodological.	Jacob, Cindy, and Megan
1 of them responded that science is skeptical in its answers.	Cindy
2 of them responded that science is logical.	Jacob and Cindy

The above categories of science philosophies represent the diversity of philosophies held by students in SCIED 411. In other words, five of the participants' (Frank, Cindy, Jacob, Liz, and Megan's -- all pseudonymous --) overall science philosophies had the same categories with the ones I crafted from the 20 students' responses (all the students in class who completed the questionnaire). It is essential to mention here that my primary interest in utilizing the philosophy of science questionnaire was to study students' science philosophies. Students as individuals was my secondary interest. Therefore, the above categorization explains about the representation of the philosophies, but not about the individuals.

In summary, in the beginning of the Fall Semester of 2003, five of the participants were purposively chosen to represent the group of students in SCIED 411. Two of these five participants were male, and three of them were female. Four of them were undergraduates and one of them was a graduate student. The profiles and a detailed description of each individual are represented in the within case analysis part of Chapter 5, Findings of the Study.

4.3.3 Rationale of Dimensions of Interest

The purpose of this study is to explore the ways in which and the extent to which college students' conceptions of the sociological NOS are influenced by their participation in the activities of the CPR project. There were two sub-questions posed: (a) How do college students' NOS conceptions change after participating in the CPR project? And (b) What are college students' experiences with the activities of the CPR project?

The conceptual criterion for selecting participants was students' philosophies of science. I did not use students' conceptions of the NOS and the establishment of scientific knowledge as selection criteria because the purpose of my pre-interviews was to identify participants' pre-conceptions of the NOS and the establishment of scientific knowledge. I did not want to replicate my pre-interview findings with the selection criterion. Based on similar assumptions in the literature (Atkins, 1997), I assumed that there is a relationship between students' philosophies of science and their conceptions of the NOS and the establishment of scientific knowledge.

A comparison of different pre-conceptions of the NOS with post-conceptions after the intervention helped me explore "which" and "how" different pre-conceptions were changed because of the CPR project. I selected participants who did not hold a particular philosophy of science, such as science is/should be objective or search for absolute truth. I wondered how the CPR project influenced understanding of the NOS aligned with various philosophies of science. For this reason, I selected some of these participants knowing that they already believed science is not absolute truth of knowledge (i.e. science is subjective or skeptical).

I also did not want my study to be influenced by participants' gender (male or female) and educational background (undergraduate or graduate student). Patton (1990, p.169) states that the rationale of "purposeful sampling lies in selecting information-rich cases for study in depth." Even though I cannot be sure whether gender and education determine students' conceptions of the NOS, in order to avoid any undesired biases, I selected participants of both gender, of different educational backgrounds, and who held different philosophies of science.

4.4 Instrumentation

I designed a semi-structured NOS interview protocol in order to explore participants' understanding of the selected features of the NOS. The first version of this interview protocol, with revisions made during a pilot study, is represented in Appendix B. Related literature has been utilized in the design process of this protocol (e.g., Bell, Lederman & Abd-El-Khalick, 2000; Schwartz, Lederman, & Crawford, 2000). In the interview design process, the tentative, empirical, value-laden, subjective, human endeavor, and sociological characteristics of science were selected as focal features of the NOS (Yalvac & Carlsen, 2002). I chose these tenets of the NOS because they are indicated as the essential tenets of the NOS in both current science education research (e.g., Lederman, 1992, 1998) and in the field of Sociology of Scientific Knowledge (e.g., Sismondo, 1993). Dr. Carlsen helped me to revise and finalize the first version of this protocol before and after the pilot study.

The semi-structured NOS interview protocol was first designed in the Fall semester of 2001. It was used in the next two semesters. Patton (1990), Merriam (1998), Creswell (1998), and Denzin and Lincoln (2000) advise that interview protocols should be practical, allowing the researcher to collect useful information. In this study, I am particularly seeking students’ understanding of how scientific knowledge is established. Therefore, after the pilot study, I revised the interview protocols in light of the analysis of the pilot study (Appendix C). Several questions used in the first design were not helpful in the investigation. For example, “What is a scientist?”, “What is a scientific experiment?”, “Do you think you are a scientist?”, “Do you think science teachers should think like scientists?” were omitted because these questions were not seeking an understanding about the sociological NOS. The commonalities I crafted from the participants’ responses to these omitted interview questions were not directly related to their experiences with the activities of CPR project. On the other hand, there were some questions that emerged from the pilot study that were added to the proposed interview protocol.

The new items added to the interview protocol were: “In your perspective is science a social activity? How? or Why not?”, “… In what ways do scientific facts change?”, “… If humans did not exist in the world, would scientific facts still exist? Could you explain your response?” and “… If humans did not exist in the world, would other kinds of facts still exist? Could you explain your response?” These additional items were the sub-questions of the protocols, so they were only directed to participants when the conversation required.

I found the aforementioned items particularly helpful. For example, pilot study participants had the tendency to relate “scientific facts” with “Nature” itself rather than viewing them as “propositions” in a scientific paradigm. When I asked my interviewees to compare scientific facts with non-scientific (pseudo-scientific) facts, some of them restated their understanding of scientific facts.

Similarly, another semi-structured CPR interview protocol was prepared in order to illuminate students’ experiences with and views toward the CPR system. The analysis of the data collected in the pilot study did not require revision of the items of this protocol. I could have crafted the important commonalities in participants' shared experiences with the CPR project. Some of these commonalities were in the dimensions of like/dislike, confidence, and usefulness/acceptance of the review, all of which were related to their experience with the CPR project (Yalvac & Carlsen, 2002). The final version of this semi-structured NOS interview protocol is represented in the second parts of Appendices B and C.

There were some other questionnaires and forms (e.g., Appendices D to F) that participants completed through their participation in the project. Most of these questionnaires and forms have been designed by Dr. Carlsen and have been utilized since the project was first implemented. These questionnaires and forms were used as sources for the secondary data in the present study.

4.5 Parallels in Research Questions and Data Sources

In this study, I explored the ways in which and the extent to which college students' understanding of the sociological NOS are influenced by their participation with the activities of the CPR project. There were two sub-questions utilized to serve that purpose. Table 4.2 summarizes the research questions (sub-questions) and associated sampling strategies and data collection resources.

Table **4.2**: Parallels in Research Questions and Data Sources

Sub-research Question	Sampling Strategy	Primary Data Collection	Secondary Data Collection
1st	Maximum Variation	Semi-structured Interviews (Pre and Post)	- Philosophy of Science Questionnaire (Pre and Post)
2nd	Maximum Variation	Semi-structured Interview	- Students Demographic Questionnaire - Final Student Questionnaire

For the first and the second sub-questions, maximum variation sampling was used to select the participants. In addressing the first question, data were collected by interviewing the participants. The philosophy of science questionnaire was used as a secondary data resource and in triangulating the interview findings. For the second question, data were also collected through interviewing the participants. Secondary resources for the second sub-question were student demographic questionnaire (Appendix E), and final student questionnaire (Appendix F).

4.6 Time Sequence of the Research

The philosophy of science questionnaire was administrated on two different occasions, once in the beginning (pre-administration) and once at the end of the Fall 2002 Semester (post-administration). I interviewed each of the five participants before the activities of the CPR project were implemented (pre-interview). In these pre-interviews, only the semi-structured NOS interview protocol guided the conversations. After the CPR project was completed, I interviewed the participants a second time (post-interview). In the post-interviews, in addition to the semi-structure NOS interview protocol, the semi-structure CPR interview protocol was used. The time sequence of the present study with the primary data collection instruments is represented in Figure 4.1.

<table>
<tr><td>Philosophy of Science
Questionnaire
(Pre-administration)</td><td rowspan="2">College
Peer Review
Project</td><td>Philosophy of Science
Questionnaire
(Post-administration)</td></tr>
<tr><td>Semi-structured NOS
Interview Protocol
(Pre-interview)</td><td>Semi-structured NOS
Interview Protocol
&
Semi-structured CPR
Interview Protocol
(Post-interview)</td></tr>
</table>

Figure **4.1**: The Sequence of the Present Study.

The human research subject forms of the present study were approved by the Office for Regulatory Compliance at Pennsylvania State University. The copies of these forms are included in the Appendix I- Students On-line Consent Form and in the Appendix J- Student Consent Form for Penn State Students.

4.7 Data Collection and Managing

One way to address peoples' understanding is to ask them to describe their own perspectives, that is, understanding and thinking that would most probably be based on-or assumed as their own experiences. By doing so, researchers can illuminate the possible meanings that the subjects indicate by analyzing the specific statements and the themes they respond to. By interviewing the participants, researcher have an opportunity to analyze people's understanding about a specific phenomenon.

Patton (1980) suggests that the interview in qualitative research should make an attempt to understand the world, to unfold how people describe their experiences, and to uncover the world that they lived in prior to scientific explanations. In this study, the interview schedules were constructed in such a way that individuals could describe their own understanding and thinking of the NOS, as well as their experiences with the instrumentations of the CPR project. Dexter (1970) describes interviews as "conversations with a purpose." In this research, semi-structured interview protocols guided the conversations. Through the conversations, the predetermined questions as well as the emerging ones were posed to the interviewees.

The primary data of this study were collected through interviewing participants. The pre-interviews lasted approximately 45 minutes and the post-interviews approximately 60 minutes. All of the interviews were video- and audio-taped. I audio-taped the interviews in order to back up the conversations recorded in videotapes. The data stored in videotapes were transcribed with the use of a C-Video system. The main advantage of the C-Video system is that it enables researchers to navigate through the videotapes whenever a verbatim datum (or a code) is selected on the text through the synchronized use of a computer and a VCR from one source. A disadvantage of using C-Video system is, the videotapes are played lots of time, and they may easily break up. Backing up the data in audiotapes was therefore necessary.

The secondary data, some of which were used to validate the interview findings, was collected through the use of the on-line questionnaires (Philosophy of Science Questionnaire- Appendix A, Students Demographic Questionnaire- Appendix E, and Final Student Questionnaire- Appendix F).

After the transcripts of the interview data were completed, I analyzed the verbatim utilizing a constant comparative method (Glaser & Strauss, 1967).

4.8 Method of Analysis: Constant Comparative Method

The constant comparative method described by Glaser and Strauss (1967) involves developing a set of categories derived from the leading pieces of information collected. The researcher compares the incidents applicable to each category. When it is appropriate, the researcher modifies these categories so that the most identified incidents fit within a reasonable set of categories. After the categories are identified, they are examined and integrated with descriptions of their properties in order to state a more general theory.

In the subsections that follow, I describe the steps taken in the constant comparative method to illustrate how I analyzed the interview verbatim and connected it to my study propositions. My purpose in utilizing the constant comparative method was not to develop a new theory, but to associate participants' responses to the study propositions with a thick description of their conceptions of the NOS.

4.8.1 Comparing Incidents Applicable to each Category

A researcher starts by coding each incident in the data into as many categories of analysis as possible. This coding is twofold: categories emerge from the data and data are shown to fit into existing categories. Coding can be accomplished by noting categories on margins next to the incidents. In the present study, while I was reading the interview verbatim, I noted emerging codes next to each incident. Participants' responses to the interview items were the incidents of the verbatim. For example, in Figure 4.2 there is an interview excerpt and the code I noted next to it (facts change). The incident interviewee describes is "scientific facts are subject to change" and the category that incident belongs to is "scientific facts are tentative."

Interviewee: Yes, they [scientific facts] change. Sometimes slowly over time as we build new knowledge, or understand something better and I guess sometimes quickly. Some kind of revolutionary science takes place.	***facts change***

Figure **4.2**: An Example of an Interview Excerpt and the Code Researcher came up with.

Glaser and Strauss (1967, p. 106) suggest that "while coding an incident for a category, compare it with the previous incidents in the same and different groups coded in the same category." After I had written several categories associated with several incidents, whenever I read a new incident and wrote an emerging code for it, I compared the categorization for that code with the other incidents. This process requires the researcher to read the verbatim several times.

A constant comparison of the incidents generates theoretical properties of the category. Meanwhile, the researcher constructs a continuum of a category: with its dimensions-“its major consequences, or relation to other categories” and limitations-“conditions under which the category is pronounced or minimized” (Glaser & Strauss, 1967, p.106). In the analysis, after I coded several incidents, in my next round of reading the verbatim, I started to compare the incidents with each other. Sometimes different categories associated to different incidents diverged, so I collected these incidents under one category that best explained the whole. In some other instances, I have realized that different incidents and associated categories converged. This variation of categories aligned with their incidents helped me to illuminate the dimensions and the limitations of the categories I had been working on.

For example, the second time I read one interview transcript, I changed the code “facts change” to “scientific knowledge changes.” Figure 4.3 represents my second decision about an incident I had coded previously (see Figure 4.2 above). This time I deleted the code “facts change” and wrote it as “scientific knowledge changes.” The category explaining that code was changed from “scientific facts are tentative” into “science is tentative.”

Interviewee: Yes, they [scientific facts] change. Sometimes slowly over time as we build new knowledge, or understand something better and I guess sometimes quickly. Some kind of revolutionary science takes place.	~~***facts change***~~ ***scientific knowledge changes***

Figure **4.3**: An Example of Changing a Written Code

The reason that I often re-stated the codes and the categories describing them was that I realized the commonalities (as well as the differences) of various incidents within and across participants' interview transcripts. Various but related incidents sometimes converged under the same category. I continued to read the transcripts a few more times, until I personally felt that there would be no more changes.

Glaser and Strauss (1967, p. 107) discuss two types of categories used by researchers: (a) the researcher constructs some categories derived from participants' statements, and (b) the researcher notes categories abstracted from the language of the research situation. The categories abstracted from the research situations are used as current labels for the behaviors explained by the participants. The categories a researcher constructs tend to be explanations of behaviors the participants demonstrated. Therefore, there is an *explanation* (categories from the 1st type) of a *particular behavior* (categories from the 2nd type).

In the present study, *particular behaviors* were the terms used by participants in speaking about the NOS. The *explanations* I made about these terms are the categories I constructed. For example, when I read an excerpt such as "I think science is something all around us and it's always changing, it's not definite even the definite things can be challenged…", I noted the term "changing" next to this incident as a code. The representation of this "changing" code and its categorization was a *particular behavior* (a particular understanding about the NOS). As I went through the constant comparative of the incidents, I replaced the code "changing" with another code "tentative." "Tentative" was used as a category to *explain* that *particular behavior*; a belief that "science is always changing, it's not definite even the definite things can be challenged."

During the coding process of the incidents, a researcher may start to question if the emphasis of a category is correct. Glaser and Strauss (1967, p.107) suggest that the researcher stop coding and record a memo on the problem. This way, the initial freshness of the researcher's theoretical notions are preserved and can be used to address the confusion. When I was confused regarding emphasis of a category associated to an incident, I often wrote memos- a short explanation of what I had understood- about the incident I read.

For example, when I was reading one of my interviewees' verbatim, I got confused and could not come up with a meaningful code, a plausible explanation, or a category to link the incidents. Figure 4.4 represents an excerpt that I had difficulties coding. I considered Glaser and Strauss's (1967) suggestion; I stopped coding and recorded a memo. I was able to read other incidents and continue working on the analysis. When I came back to read that particular incident, I read the memo and was able to come up with a solution. I chose to directly report what I have learned from that incident regardless of its missing connections with the other categories. Eventually, I came across other incidents that could be linked to that new category that emerged from the recorded memo.

Interviewee: In philosophy we are not really trying to prove anything [like science]. Well, you never prove anything in science. But you are not proving anything in philosophy, I have never taken any philosophy class, so I, science is more… we are not sure whether it's right or wrong.	***Memo: I haven't came up with a code or a related category. Cindy says "you never prove anything is science" and I don't know what she was explaining. If in philosophy there is no proof, then how is it different from science in which you can never prove anything either.***

Figure **4.4**: An Example of a Recorded Memo When I had Difficulty in Coding

Another suggestion of Glaser and Strauss (1967, p. 109) is "since an incident can be coded for several categories" writing memos will help "to use an incident as an illustration only once, for the most important among the many properties of diverse categories that it indicates." In my analysis, I came up with fewer but more tangible categories as I read the incidents along with the written memos about them. For example, I was able to come up with two codes for the incident presented in Figure 4.4 after I read other incidents. One of these codes was the "empirical" characteristic of science that differentiates science from philosophy, and the other code was the "falsiability of scientific claims," as Popper (1959) explained it. The "empirical" characteristic of science is not evident in the incident presented in Figure 4.4. However, after reading the other incidents and with a thorough analysis of them, I found that the interviewee was making the argument that science follows logic and has a particular method that philosophy does not have. The empirical characteristic of science was embedded in her words; “in philosophy we are not really trying to prove anything,” and could only be uncovered in conjunction with the other incidents she described.

4.8.2 Integrating Categories and their Properties

As I kept reading the interview transcripts, I noticed that codes and categories varied. Glaser and Strauss (1967) suggest that as the categories vary “constant comparative units change from comparison of incident with incident to comparison of incident with properties of the category that resulted from initial comparisons of incidents” (p.108). For example, students’ responses to the question: “If humans did not exist in the world, would scientific facts still exist? Could you explain your response?” is one incident and it has associated codes. Another incident was students’ responses to the question: “If humans did not exist in the world, would other kinds of facts still exist? Could you explain your response?” along with its associated codes. As I proceeded with my analysis, I not only compared the incidents but also I compared the incidents with the categories that they emerged. By doing so, the properties of the categories were integrated “that is related in many different ways, resulting in a unified whole.” (Glaser and Strauss, 1967, p.109). In my analysis, there were categories with the titles: “scientific facts” and “other kind of facts.” After utilizing Glaser and Strauss’s suggestion about “integrating categories and their properties,” I decided to combine the categories “scientific facts” and “other kind of facts” under one category, “facts.”

4.8.3 Delimiting the Theory

As the categories became more tangible and their connections with the study proposition became more visible, I was able to reduce the number of categories and thus their emphasis. This helped me to connect fewer categories to the study propositions. However, sometimes I was unable to connect a category with another. I had ended up with some categories and associated incidents with no connection to other categories and their incidents.

Glaser and Strauss (1967) mention that *reduction* can be done as the researcher discovers underlying uniformities in the original set of categories or their properties. I deleted some of my codes and sometimes categories that did not seem to fit with another code or category. Glaser and Strauss (1967, p. 111) agree that another way of delimiting the theory is to reduce the original list of categories for coding. Otherwise, the data will be overwhelming. This reduction should be made within the boundaries of the study propositions. In the final stages of my analyses, the boundaries of my study propositions became students' understanding regarding the tentative, empirical, subjective, value-laden, human endeavor, and sociological NOS. For example, one of the interviewees talked about a news report he had heard on TV, and made a comment that he was surprised how "ordinary people don't have a good grasp of what science is or what its objectives are." I first coded this incident and linked it to some categories, but in the final stage I deleted the codes and their links after concluding that they were not within the boundaries of my research propositions.

As I became more familiar with the data and comfortable with the categories associated to study propositions, I was able to add more incidents to these categories.

Glaser and Strauss (1967) call this process of adding incidents to categories that were not previously added before as *saturation* of categories.

It was relatively easier to analyze participants' experiences with the project than to identify their conception of the NOS. I followed the same steps listed above in categorizing participants' experiences with and views toward the project activities.

4.8.4 Writing the Theory

Glaser and Strauss (1967, p. 115) mention that at the end of the coding process, when a researcher is convinced that an analytic framework forms a systematic proposition, she can start to write that proposition. I have written each of the participant's pre and post-conceptions as the final propositions of my analysis. Until then, I was able to compare these conceptions and conduct with-in case and cross-case analyses. I performed with-in case analysis for each participant in order to describe the changes in participants' conceptions of the NOS and her experiences with the project activities. Next, I did cross-case analysis between the cases in the contexts of changes in participants' conceptions of the NOS and their experiences with the project activities. The findings of these analyses are represented in Chapter 5, Findings of the Study.

Glaser and Strauss (1967, p. 115) mention that the constant comparative method can yield either discussional or propositional theory. In discussional theory building, researcher identifies as many properties as can be associated with a category. In propositional theory building, a researcher writes formal propositions about a category. Because my primary purpose is not to build a theory but rather to illustrate the existence or absence of study propositions regarding the NOS, I have chosen to describe my findings by writing formal propositions for each category. To help the reader to follow the propositions effectively, I added conceptual diagrams summarizing the propositions. I only created conceptual diagrams for the NOS interview findings. For the experiences with the project activities, I described the propositions, reasoning that the commonalities represented were relatively easier to understand as compared to conceptions of the NOS.

4.9 Criteria for Validating Findings

The primary data for this study were collected through interviews. The secondary data resources, as mentioned previously, were used to validate the findings of the interview analysis.

In qualitative research traditions, the credibility of the data can often be established through triangulation of the analysis (Creswell, 1998; Merriam, 1988). Triangulation involves corroborating evidence from different sources to shed light on a theme or perspective. For the students' conceptions of the NOS, I referred to participants' responses in the philosophy of science questionnaire in order to validate the interview findings. The data collected from the pre and the post administrations of the philosophy of science questionnaire were compared and contrasted with the categories and associated propositions of participants' responses in the interviews. After each propositional description of an interview session, I presented an in-depth discussion to explain the credibility of the findings.

In order to validate the interview findings regarding students' experiences with the project, I looked to the students' responses to the final questionnaire that was administered on-line. This questionnaire posed questions to those of the interview protocols, and searched for similar student experiences. I did not follow with a discussion of these findings reasoning that students' experiences were not hidden, but were directly spoken. The questions that I posed to participants to explore their experiences were direct questions. On the other hand, for the NOS conceptions, the intention of the interview items was often embedded in the questions and that made it harder to uncover propositions from the participants' responses.

4.10 Reporting Findings

Patton (1990, p.385) mentions that in case studies with several participants, the analysis begins with the individual case studies and follows with a cross-case pattern analysis of the individual cases. Case data consist of all the information a researcher has about each case. In the present study, I considered each participant's NOS conceptual ecology as a case, and performed case analysis (with-in case analysis). In these analyses, students' pre and post-conceptions of the NOS were identified, and their changes in conceptions of the NOS were explicated. Next, I described student's experiences with the CPR project. After each case was studied separately, a cross-case analysis was performed. The phenomena investigated in the cross-case analysis were students' experiences with the project activities and changes in their conceptions of the NOS. The findings of these analyses are represented in Chapter 5-Findings.

As findings, I report changes in students' understanding of the NOS and the commonalities of their experiences with the project activities. Because this study is a qualitative inquiry, I report my findings qualitatively rather than with numbers or with statistical significance values.

4.11 Researcher Background

In this section, I summarize my educational background in the field that constitutes the foundations of the proposed study.

My professional career can be described as having two parts: my M.S. and Ph.D. studies. After obtaining B.S. degrees in Physics and Physics Education, I worked for three years as a Teaching Assistant in the Science Education Department at the Middle East Technical University (METU) in Ankara. Meanwhile, I completed my M.S. degree in the field of Science Education. Throughout these three years, my teaching experience was primarily with undergraduate students. The courses I taught included a "Physics Laboratory Projects" course offered to Science Education undergraduates, "Digital Electronics Laboratory" and "Visual Basic Programming Language" courses offered to Technology and Computer Education undergraduates, and a "Computer Assisted Instruction in Education" course for education undergraduates.

I was also assigned to be a student teaching supervisor and an advisor for the science education undergraduates. In the last two years of my study for my M.S. degree, on the weekends and in the evenings, I taught secondary school science and high school physics classes in a private office that offered tutorials to K-12 students. Students enrolled in these tutorials had relatively high social income parental status and all were from private high schools in Ankara. Class size was not more than five students. These small class sizes provided me an opportunity to implement various teaching/learning methods I had learned in my education classes. The primary objectives in these courses were to help students acquire scientific content knowledge. During my PhD studies at Pennsylvania State University, I taught classes of approximately 35 students in a science and technology and engineering design principles course, where I strove to implement the methods I used with much smaller classes. The primary objectives of this course were to teach students scientific content knowledge, and also the pedagogy to teach that knowledge.

For my master's thesis, I implemented a conceptual change strategy in the electric current concept at the 6^{th} grade in a private school in Ankara. The research was basically a quantitative inquiry. I could say that I was not aware of holding ontological and epistemological stances in my M.S. study. Even though I had taken one qualitative research course in the last semester of my studies at METU, I became familiar with qualitative inquiry at Pennsylvania State University.

In my Ph.D. studies in the Science Education Program at Pennsylvania State University, I have taken several classes in philosophy, history, and sociology of science and science education, and qualitative research methods. My interest in the sociological NOS was initiated by my studies at Pennsylvania State University. Dr. Bauchspies and Dr. Carlsen influenced my conceptualization of the proposed study. My readings in my classes and my communications with Dr. Bauchspies and Dr. Carlsen helped me to (re)state my ontological and epistemological stances.

I had experienced frustrations when I started to conceptualize that reality and the associated knowledge are not objective, static, and durable. However, through my studies at Pennsylvania State University, I began recognizing that reality and the associated knowledge are neither self-generating nor self-evident. Reality and the knowledge generated from this reality are human constructs. The readings I did in my classes and the conversations I had with Dr. Bauchspies and Dr. Carlsen helped me to achieve that recognition. My frustration with the concepts of non-objective, tentative, and flexible reality and the associated knowledge decreased as I began to regard myself as Subject (constructing knowledge and participating in transforming *my* world) rather than as Object (merely consuming knowledge and adapting to pre-given, unchangeable realities) (Baptiste, 2001, p. 10 - citations are in parenthesis). This was a liberating message, influencing my perspective on life and the reality that I hold.

I collaborated with Dr. Carlsen on a pilot study of the proposed research in the Fall Semester of 2001. The pilot study helped me to confirm my interest in exploring college students' understanding of the sociological NOS. The analyses of the pilot study did not show a dramatic difference in students' pre- and post-conceptions of the NOS. The significant difference I observed was in students' pre- and post-understanding of the establishment of scientific knowledge. The pilot study findings inspired me to focus on students' understanding of the sociological NOS.

As a researcher, one of my biases is that conceptions of the sociological NOS are the most important tenets of the NOS. The current science education literature on the NOS does not provide an in-depth investigation of the sociological NOS conceptions. I maintain that conceptions regarding the generation of scientific knowledge (e.g., the sociological NOS) should take precedence over conceptions regarding the scientific methods (e.g., science is empirical). I believe if someone does not hold any assumptions about how knowledge in general is produced, then she will not be able to analyze the knowledge itself critically. In science, if someone does not participate in generating scientific knowledge and does not have a chance to conceptualize an understanding from her lived experience, she will not be able to critically analyze scientific knowledge and its influence on technology and society.

Because of my bias in favor of the establishment of scientific knowledge and because of the gap in the literature, in the present study, I particularly focus on students' conceptions of the sociological NOS.

Chapter 5

Findings of the Study

5.1 Overview

This study is a collective case design. In a collective case study design, the researcher collects data on more than one participant in order to gain greater insight into the phenomena under investigation. Stake (2000) suggests that even though in collective case study design, participants are not the primary interest, it is worth considering each participant as a unique case and perform analysis accordingly. The phenomena I study are changes in college students' conceptions of the NOS and their experiences with the CPR project. In this study, I worked with five participants. In the analysis, I considered each participant's conceptualization of the NOS and experiences as a unique case. Therefore, in the first section, I perform a within-case analysis for each participant. In this within-case analysis part, each of the five participants' understanding of the NOS is considered as an individual case, and the changes in their conceptions of the NOS and their experiences with the CPR project are explored.

In the second section, I perform cross-case analyses. These analyses start with the comparison of changes in participants' conceptions of the NOS derived from the within-case analyses and follows with the commonalities of participants' experiences with the CPR project. In both of these parts, participants' same or different conceptions are investigated. In this chapter, I discuss similarities and differences among the participants with respect to changes in conceptions of the NOS and their experiences with the CPR project.

5.2 Within-Case Analysis

The within-case analyses begin by highlighting the commonalities of all participants. I focus on one individual at a time, first presenting relevant demographic information and later reporting their pre and post-conceptions of the NOS as identified by the semi-structured NOS interview protocol. For additional clarifications that will help reader to follow the study propositions, conceptual diagrams are presented at the end of each sub-section. In the following sub-sections, participant’s pre and post-conceptions of the NOS identified by the interview protocols are triangulated, utilizing participants’ responses to the pre and the post philosophy of science questionnaire. Changes in participant’s conceptions of the NOS are discussed. Finally, I describe experiences with the CPR project as reported in the post-interview sessions. Participants’ responses to the final questionnaire items are also addressed.

5.2.1 Commonalities of Cases

All five participants described in this study were enrolled in a Science Education Program at Pennsylvania State University. None of the five participants considered him or herself a member of an African-American, Hispanic, or Native American minority group. English was the first language of all participants.

5.2.2 Case 1: Frank

5.2.2.1 Frank's Demographic Information

Frank, a pseudonym, had a Bachelor of Science (BS) degree in the field of Biology at the time he was enrolled in the SCIED 411 course. Of all five participants, Frank had the broadest research experiences in a setting rather than a conventional classroom. After he had completed his BS degree in Biology, he worked for Fishing Life Services, in Florida. He taught rural farmers in the Republic of Zambia how to raise fish. During the fall semester of 2002, he was working part time for the State Government in the Pennsylvania Fish and Boat Commission. As he mentioned in the pre-interview, his wife was teaching at the university in which he was enrolled. He was not able to find a full time job in the field of Biology in State College, which is basically a university town. Therefore, he decided to pursue a teaching certificate in Science Education at Pennsylvania State University. During the Fall 2002 semester, he was enrolled in a program for graduate students and was taking classes required for a teaching certificate.

5.2.2.2 Frank's Conceptions of the NOS before the Activities of the CPR Project (Pre-interview Findings)

In the pre-interview, Frank reported that science was *empirical*, *subjective*, *tentative*, *value-laden*, and a *human endeavor*. He referred to the *sociological* NOS in some of his explanations of science. Frank's pre-conceptions of the NOS are summarized in Figure 5.1 and described below.

Frank defined science as “exploring the unknown, trying to categorize, trying to put structures the things that are seem random, or the things that we don’t understand.” In this definition, science was portrayed as a process to understand and explain the Nature, particularly the unknowns, in a systematic and structured way. Frank described science in reference to its *empirical* characteristic. Observing the Nature and collecting evidence are what he considered necessary practices for making scientific predictions (Figure 5.1). Frank stated:

> [In science] you are collecting evidence and you are observing things in nature and through this you are making predictions.

In the pre-interview, Frank expressed his view that a goal of science is to achieve complete objectivity. He told me that science should be objective and the role of scientists is to achieve objectivity (Figure 5.1). Frank later elaborated on the objectivity of science and argued that science was not completely objective. He exemplified the *subjective* characteristics of science describing how bureaucracy maneuvers scientific practice and how this influenced his current employment status. In the following comment, he relates his experience to explain why science is not always objective.

> From a personal experience I have seen, I guess, just through working for the state, federal government, you can apply for grants, or federal money. Even considering the fact that I am having difficulty getting a full time job in the field, once the funding gets going, that gets directed down, politically from the top down, which is affecting what science is practiced, and what isn’t, and that’s just an example. If the head politician that’s selected, his platform is reducing bureaucracy or something like that, he will obviously cut jobs, and certain jobs are going to get cut. If he doesn’t deem important -so let’s say the governor isn’t interested in the management of the fisheries in the state, he might decide, oh let’s put in less [funding], and that changes science. That’s not very objective.

The above excerpt reveals that Frank believed that the planning and the design stages of science are influenced by the interests of society, and in this case, particularly by the government (Figure 5.1). The *value-laden* characteristic of science is also addressed.

Frank mentioned that even though scientists, in their practices, try to be objective, it is impossible to be completely objective. He asserted that complete objectivity cannot be achieved because of human nature. He stated:

> I think for the most part, most scientists try to be objective, but even in their personal believes, I mean, it's almost impossible that not to bring these beliefs with you, into what you are doing. It's like in the brain, it's like your subconscious, something.

Frank discussed the *sociological* NOS in the pre-interview. He referred to the peer review aspects of science in order to illustrate how scientific results are shared by the scientific community (Figure 5.1). He stated:

> …the results from these [scientific claims] are seen by everyone, and they are reviewed by other experts.

Frank asserted that a goal of reviewing one another's work is to check the reliability of the knowledge represented in scientific results. This would eventually increase the objectivity of scientific knowledge (Figure 5.1).

Frank believed that scientific facts are the best explanations of what is happening in world. He reported that his conceptions about scientific claims in general and scientific facts in particular have changed since he began studying in his program. He stated:

> I guess, it's interesting for me because after starting school, I've kind of, several of my classes [in Science Education Program at Penn State] forced me to think in a way that I didn't as a scientists. One of those ways is I always kind of just, I was always interested in science, and I always accepted that, okay that makes sense. You know, if you took a physics class -how intuitive physics explain everything and makes it so much easier to grasp it. That's my personal comment. Now, when I took some of the classes here I realized, it kind of opened my mind, scientific fact kind of really means explanations of something. How can anyone person or even a group say, you know, a fact by a definition, if you look at and read the definition of it? But fact in science is just the best explanation that goes to any level, like theory, a law or whatever. It's just all how humans perceive what's happening, and I really never thought about that.

Frank reported that scientific facts are subject to change reflecting the *tentative* characteristics of science. He told me that history illustrated that scientific facts have been evolved (Figure 5-1).

> Yes, I think [scientific facts are subject to change], that happens everyday. That's back to what I was saying about fact. It's just what we were perceiving, it as being the explanation in any given point of time. I mean, if you look through history, you can see the parameters, how we changed them a lot.

In the above statement, Frank implies that he perceived scientific facts as human explanations of a physical phenomenon rather than as the physical phenomenon itself. This view is explicit in another of his responses:

> We are the ones creating and trying to explain these [scientific facts], so the pen will still fall but no one would be trying to explain it.

Frank explained that physical phenomena would still exist but the explanations for them (scientific facts) would not, if humans did not exist in the world. This is evidence that Frank perceived scientific claims as *human endeavor* rather than as absolute truths of Nature (Figure 5-1).

Frank described the process of generating scientific knowledge in reference to the *empirical* and the *sociological* NOS. He pointed out that scientists cannot ensure the absolute objectivity of their scientific claims. Scientists can only come up with their best explanations of scientific phenomena through experimenting and observation, and by having other scientists in the field review these explanations. Frank stated:

> They [scientists] can't be one hundred percent sure [about their conclusions] but they can through statistics, through observations, through what is already being done, and building on that, through other experts looking at it. I mean, that all just built to the strength of the explanation, but I wouldn't say, you know, it's impossible to prove anything, you know.

The above statement reveals that Frank had an understanding of the *sociological* NOS prior to the activities of the CPR project. His description of how "other experts" would look at the scientific claims supports this kind of understanding.

In the pre-interview, Frank expressed that science was a social activity. I suppose Frank's past and present research experiences helped him to articulate the social aspect of scientific activities in terms of society's interest. He stated:

> It's all interrelated. It's like back to the issue of funding, everyone's interest is coming into play -what science has done what science hasn't. Scientists try to, in a sense, be businessman. They are trying to sell that this is important to society, and then the final project is always judged, even directly or indirectly by society.

The above statements reveal that Frank's understanding of science as a social activity was based on how society interacts with the knowledge generated by the scientific community. He did not mention that scientists were socially constructing scientific knowledge within their communities of practice.

Frank was aware that scientists work in groups and interact with each other. Even though I did not ask any questions on this issue, during the conversation, Frank criticized school science as not representing the *sociological* NOS. He stated:

You know, in a project for anything, it's always interaction with other experts. It's interaction with non experts. You know, depending on what you were doing, I guess. The last time that I ever worked on a science related project that was individual thing I was probably in high school. I don't know, I find it interesting, that now, things in education classes, in my high school at least, we usually work alone and get to report in science fair project, and stuff like that, and it's not like how it really is in real world.

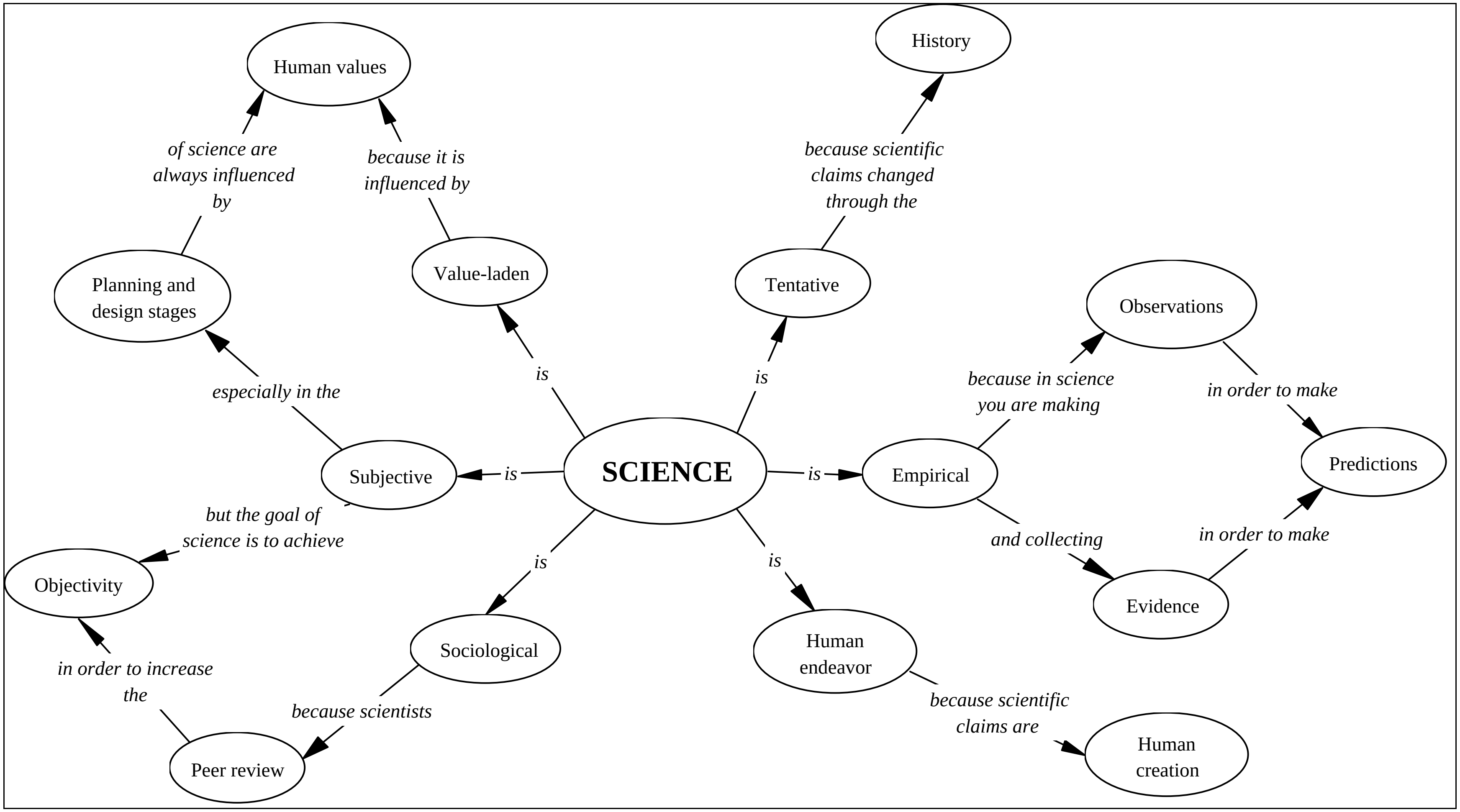

Figure **5.1**: Frank's Pre-conceptions of the Nature of Science.

5.2.2.3 Frank's Conceptions of the NOS after the Activities of the CPR Project (Post-interview Findings)

In the post-interview, Frank described science *as empirical, subjective, tentative, value-laden,* a *human endeavor,* and *socially constructed*. He explicitly referred to the *sociological* NOS in his portrayal of science. Frank's post-conceptions of the NOS are summarized in Figure 5.2 and described below.

After the activities of the CPR project were completed, Frank defined science as "is how we go about exploring things that we don't understand in Nature and around us." The words he used "how we go about" before "exploring things" imply that Frank perceived science is a way of exploring Nature, and in some respects as it is a choice we make. He addressed science as "understanding, applying, and explaining" in what follows:

> I came across a definition that I really liked in the 411 class. In one of the readings where -I think, he was a physicist- who said that science is understanding, applying, and explaining. Those three words I think, in terms of someone who is going to be a teacher, are pretty powerful. You know -applying, understanding a phenomenon, and then explaining to others, and then applying it to be useful.

In the above statements, science, defined in reference to "understanding, applying, and explaining" aspects, is a cognitive activity. I argue that that definition does not include the social aspects of science. It rather presumes science as a static entity (a body of knowledge) that can be understood, applied, and explained. Defining science as "understanding, applying, and explaining" implicitly disregards the *sociological* NOS. Science defined in such a way can be easily misunderstood and seen as an individualist practice as opposed to having characteristics of collectivization (Ziman, 1983). I do not think Frank was aware that the social aspects of science were not recognized in that definition because he later re-addressed this explanation and argued its antithesis. His responses to the emerging interview questions better illuminated his understanding of the social aspects of science. In those responses, he stated that science did not merely consist of “understanding, applying, and explaining.” The following comment demonstrates his understanding.

> I mean, if you look at the history of science, you know, no one has ever made a great discovery or great invention that was isolated. I can give an example -like a desert island, you are by yourself. There is no one else. If you make some kind of scientific discovery, and it's just you on this island, what good is it [science], you know? Maybe it helps you *understand* and *explain* and *apply* something overall, but you know, why it's a social enterprise because of that fact, and also that science does not happen in laboratory by someone by themselves, it usually takes, it's a construction of knowledge on top of old knowledge, and revising it, and changing at it; coming up with new ideas that may replace old ones. And that requires social aspects of human nature.

In the above excerpt, Frank described science as a collectivized practice rather than an individual practice (Figure 5.2). Frank included the social aspects in his definition of science, explicitly mentioning that science was not practiced by one individual isolated from others.

Frank explained his view of the *sociological* NOS in reference to the human construction of knowledge. He stated:

> I don't know what or how I answered this question last time, but the way I am thinking or feeling today, I would say no [scientific facts would exist if humans did not exist on the earth], because it is -I mean, science is a human design or construct. I mean it’s our trying to understand, and if there was no such things like humans, you know, and I guess that sets us apart from the animals, we are trying to understand something. We are not just going through everyday life, trying to survive. We are doing more than that.

Frank distinguished science from other field of inquiry with respect to the *empirical* characteristics of science. Observations of Nature, and in some aspects, scientific argumentation were considered as the characteristics of proof in science (Figure 5.2). Through observing Nature, scientists collect evidence to make scientific arguments. Frank stated:

> Science requires proof. It's kind of like, proof is the antonym to faith. See you have two completely opposite things, and in science, proof is what kind of, I think, differentiates. You need to have facts, you need to have make observations, and you need proof. So be able to make any kind of statement in order to back up you are kind of exploring, and kind of understanding.

Frank stated that scientific facts were subject to change, sometimes slowly, sometimes rapidly, because of the new findings. This implies the *tentative* characteristics of science (Figure 5.2). He was probably informed about scientific revolutions described by Kuhn (1962).

> Yeah, they [scientific facts] change, sometimes slowly over time as we build new knowledge, or understand something better, and I guess sometimes quickly like some kind of revolutionary science takes place.

In the post-interview, Frank described the legitimization of scientific facts in reference to peer review in science (Figure 5.2). In order for scientific knowledge to be checked, criticized, and understood, scientists review one another’s work.

> Well, I guess when you become an expert in certain phenomenon or field, you can't, I guess -the peer review process at least exist in our universities, and in other universities, criticizes and critiques the data you collected. Often times, I guess, they can either try to reproduce it, or to reproduce it for themselves, or it's kind of like the way the science checks, and balances itself, because you are always understood from other scientists.

After Frank introduced “peer review” in science, he further pointed out that not all published articles are necessarily scientifically correct (Figure 5.2).

> I am not saying it [peer review in science] is a perfect system, I am sure there is, you know, somebody, you know, there are papers published in certain journals, where no one probably went and actually checked up on that, and it still got published. People are probably citing it, and that might not be good science, but it seems to be a pretty, pretty good system.

In the above statement, Frank articulated that "peer review" is not a perfect system and has disadvantages especially when a paper is published without being thoroughly reviewed by others. He further commented:

> I worked in the office of the state agency that looks into state fishery management system. When we do a survey, or write a report that might have some kind of management decision that might change the actual fishing regulations or something, all the other biologist in the state have to look it over and critique it. They will say if they're not sure the way you, you know, the amount of time you collected fish on this day is right, you know, I don't think you did it right and you know, they review each other. They will say, "I don't think you can say this." This is a little bit different from the university in that the data has to be reviewed, and reported to the public, the people.

Franks thought science is the most objective way of understanding Nature but at the same time, it cannot achieve complete objectivity.

> No [science is not objective], I mean it's one of its goals, but I mean, we are human so there is absolutely no way that you can say it's completely objective. But I think it is. more objective than a lot of other ways of understanding.

Frank thought science tried to be objective because of its *empirical* characteristics (Figure 5.2). He stated:

> Just, because it [science] demands you to try to come up with a way of explaining and supporting it with data of some sort or observations that tries to help understand.

When I posed an emerging question as to whether or not peer review increases the objectivity of science, Frank did not particularly say that "peer review" was done in order to check (or increase) the objectivity of science. Rather he told me that "peer review" was performed so that scientists could check one another's work to verify scientific claims, but not necessarily to increase their objectivity. His response to my question was as follows.

> No, it [reviewing each others' work] is a way of verifying whether someone used a truly scientific way of trying to understand something, whether it was done, whether it is true science, or if it was too much, you know, it wasn't objective enough, or the data wasn't accurate enough, or something like that.

Frank enjoyed talking about science and its meaning for the public. After I completed my semi-structured interview, and asked him if he had anything to add, he commented on the public understanding of science. He told me that he is surprised by what most people think about science. Frank stated:

> Its amazing how many people don't really have a good grasp of what science is, or what its objectives are, I was just surprised. When you listen the news at night, if some reporter comes on and says, "So we found this; this causes cancer," and I think, the media is it to blame for this, because no one questions what some of the stuff is. They put it in the media about a scientist, and I guess, its mostly in the field of medicine that I hear these reports, and I think, ninety percent of the people probably gobble the stuff up without even thinking how one of this study was founded, or who did it. You know, there is no scrutiny, it seems like. The public is ignoring what really a scientist is doing. So I was talking about raw science is the system of checks and balances, and you know all other scientists are checking each other. I guess a lot of times maybe it's the scientists' fault for not making it more understood for the public instead of just among themselves. Maybe that's just what I see as the problem.

Frank invited scientists and teachers to be aware of how the public understands science. He provided some suggestions in the following comment:

> Or maybe scientists could, you know, when they do research, and publish in a journal, a scientific journal -after that document is published, its up to the media to take that document, and they can do whatever they want to do. I guess scientists have to be more responsible and realize that maybe they should communicate better to the general public about what they are doing. Maybe there is just not enough understanding of what they are really doing. There is a lot of research going at this university that the average person probably has no idea about, and it’s all being published somewhere -in some journal. Most people can pick up any given journal and might have no idea, it’s so hard to understand what scientists are accomplishing. So I guess that definition I gave -understanding, applying, and explaining; I think it's the explaining part that might be a problem. This is where teachers coming.

In the above statements, Frank commented on the scientific knowledge presented in a scientific paper. He criticized the scientific paper as not being clear enough for the public to fully understand. He proposed that teachers should help the public to critically analyze scientific claims represented in academic paper

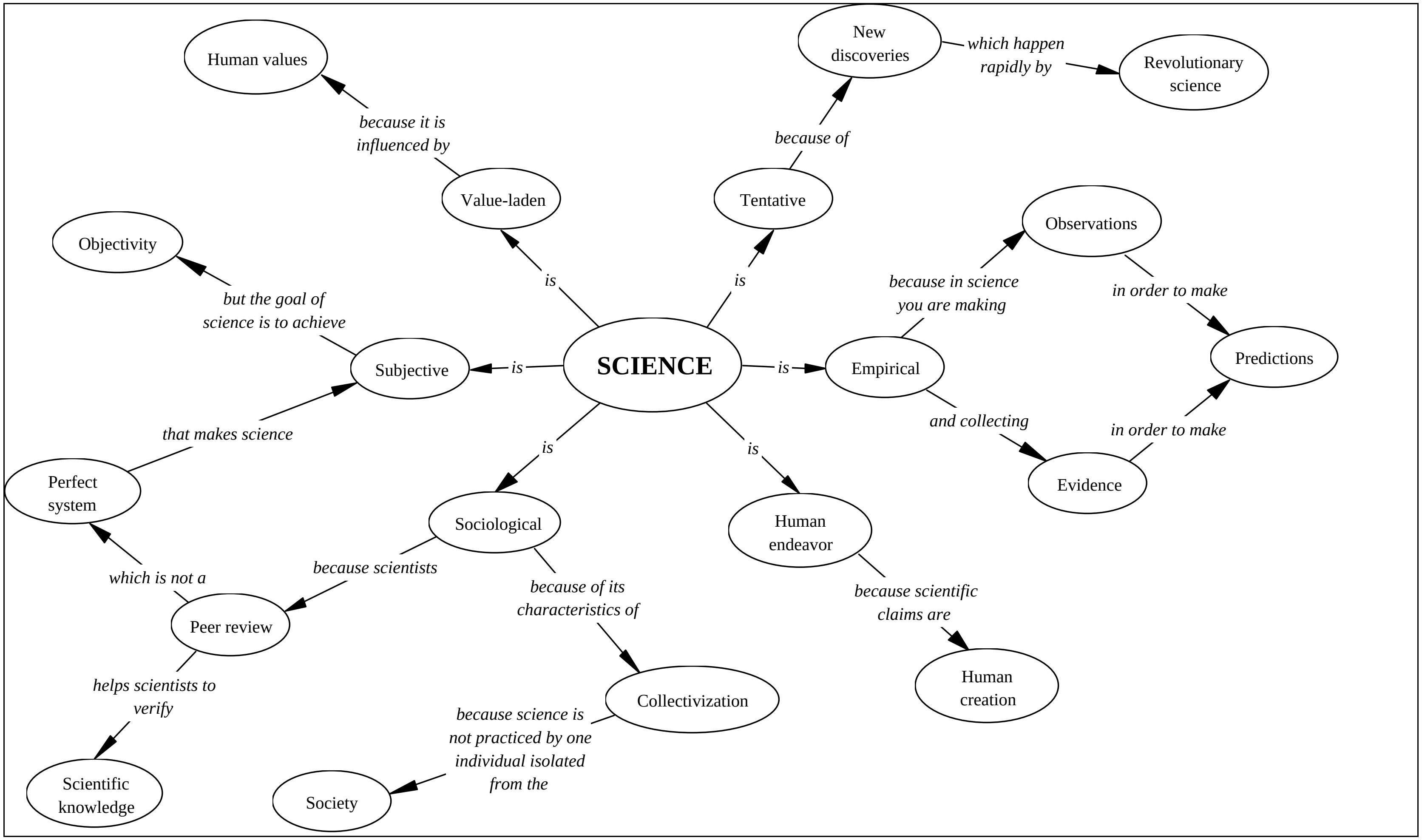

Figure **5.2**: Frank’s Post-conceptions of the Nature of Science.

5.2.2.4 Triangulation of the Interview Findings

In this section, I attempt to validate my interview findings using Frank's written responses to the philosophy of science questionnaire. There are two parts in this section. The first part is the comparison of Frank's understanding of the NOS derived from the pre-interview with that derived from the pre-questionnaire. The second part is the comparison of the findings from the post-interview and the post-questionnaire. Because the philosophy of science questionnaire was designed to explore students' philosophies of science teaching in addition to science, some of the items (items 3 and 4), which are not directly relevant to the NOS conceptualization, were excluded from the analysis for this part (for the questionnaire items see Appendix A).

Part I

The propositions I compare in this first part are about how Frank (a) defined science as an attempt to understand the Nature, (b) addressed the *empirical* NOS as a distinctive characteristic of science, (c) referred to scientists reviewing one another's work as a way to achieve objectivity in science, (d) perceived the goal of science as to be objective, and (e) commented that science was *value-laden*. I did not observe that Frank's understanding of science as he described in his responses to the pre-questionnaire differed from his responses in the pre-interview.

In the pre-administration of the philosophy of science questionnaire, Frank defined "science is trying to understand and explain processes that occur in Nature." In the pre-interview, Frank defined science as exploring the unknown and trying to categorize the things found in Nature. These explanations were consistent in that both explained science as an attempt to understand Nature.

Before the CPR project was started, Frank distinguished science from other fields of inquiry in reference to the *empirical* characteristic of science. In the pre- questionnaire, he wrote “the most important features that distinguish science are that you must prove your ideas using observation, experimentation, and empirical data.” In the pre-interview, he also addressed the *empirical* NOS as a distinct characteristic of science (Figure 5.1).

In the pre-interview, Frank told me that scientists reviewed one another’s work in order to check the validity of the knowledge represented in scientific results (Figure 5.1). Similarly, he wrote in the questionnaire “you must also subject your findings to others to double check your work.” Both the pre-interview and the pre-questionnaire analyses reveal that Frank held an understanding of peer review in science as an attempt to attain the objectivity of science.

Frank did not particularly emphasize a thorough understanding of the *sociological* NOS in his written responses to the pre-questionnaire items. He just mentioned, “Learning how to communicate together when working in a group on a common goal is quite common in scientific establishment.” In the pre-interview, he also did not comment much on the essence of scientists working in groups.

In the pre-interview, Frank pointed out that the goal of science was to achieve objectivity (Figure 5.1). He represented a similar belief in his responses to the pre-questionnaire items, stating:

> I agree partially that this [scientific reports written with no subject] is a good standard for science writing.

As the above statement reveals, Frank agreed that scientific reports should have been written with no subject. This belief parallels a realist view of science. Frank, in both the pre-interview and pre-questionnaire administrations, made similar arguments that science should be objective.

In the pre-interview, Frank mentioned the *value-laden* NOS (Figure 5.1). He also implied the *value-laden* NOS in his responses to the pre-questionnaire. He wrote:

> … but the student needs to be aware that although a report is written in this matter [scientific reports written with no subject], another human being has written it and that it is human nature to have beliefs and values.

The above comparisons reveal that the categories I crafted from the two instruments, describing Frank's conceptions of the NOS, are consistent with each other.

Part II

In this part, I compare Frank's understanding of science derived from the post-interview and the post-questionnaire administration. I utilized the aforementioned propositions listed in Part I and an additional one: "scientists reviewing each other's work as a way to legitimate scientific knowledge" which emerged in the post administrations of the research instruments.

Frank defined science as an attempt to make sense of our environment and the natural world both in the post-interview and in his responses to the post-administration of the questionnaire. In the post-questionnaire, Frank wrote:

> Science is a well-established system of logic that attempts to make sense of our environment and the natural world. My favorite definition is the one by the nuclear physicist Terrel (?), it contains three very important words that sum up what science is, understanding, explaining, and, applying. Science by this very definition implicates teachers as an important part of the process (explaining).

In the post-questionnaire, Frank distinguished science from other fields of inquiry in reference to the *empirical* NOS as he did in the post-interview (Figure 5.2). In the post-interview, he introduced his definition of science using the words “understanding, explaining, and applying” several times. Frank also used these words to illustrate the difference between science and religion; “proof is like antonym to faith” (from the post-interview with Frank). In the post-questionnaire, he wrote:

> Science is the opposite of religion. Religion requires faith and science requires evidence. It is for this reason that it is a separate realm of knowledge and thinking from other disciplines. Science isn't touchy, feely, and emotional like philosophy and art. Science, when practiced properly, is as objective as possible. It comes from the mind, not the heart.

In the post-questionnaire, Frank mentioned that “scientists working in groups is natural in science.” He also expressed the same belief in the post-interview (Figure 5.2). In both of these post assessments, he provided an example such as a lonely person in a desert could not practice science similar to how it is practiced now. The collectivization of science (Ziman, 1983), in contrast to the individualism of science, was particularly emphasized. In the post-questionnaire, Frank wrote:

> How many scientists do you know that came from a lonely desert island? Science is a social enterprise that requires us to work together. Everyone is creative in their own way. Working together is also science's little checks and balances system. Science in the real world involves creative thinking and problem solving between many different people (Pennsylvania Fish and Boat Commission) to achieve a common goal. In a science classroom members of a group may show different amounts of motivation, and some are motivated by the wrong thing (grades) instead of understanding some aspect of nature a little better.

In the post-interview, Frank expressed his belief that science should be objective, but because humans are subjective in nature, scientific practice, which is a *human endeavor,* cannot achieve complete objectivity (Figure 5.2). He commented on the need to critically analyze scientific knowledge before accepting and using it. Frank expressed a similar idea in the post-questionnaire:

> Science requires standards and detail like no other field. As an educator I think it is important to remind your students that humans are naturally subjective creatures as much as scientists try not to be. Our students need to learn to be critical consumers of science.

The above statements reveal that Frank further articulated the essence of teaching science in order to encourage students to critically analyze scientific knowledge. In the post-administration of the questionnaire and in the post-interview, while Frank was explaining science, he often referred to the *sociological* NOS addressing the socially constructed characteristics of science.

The above comparisons reveal that the categories I crafted from the post-interview are valid and consistent with the ones drawn from Frank's post-questionnaire written responses.

5.2.2.5 Changes in Frank's Conception of the NOS

Frank did not dramatically change his conceptions of the NOS regarding the *subjective, tentative, empirical, value-laden*, and *human endeavor* tenets after completing the activities of the CPR project. Frank, in contrast to the other four participants, mentioned an understanding of the *sociological* NOS in the pre-interview. However, his explanations of why scientists review each other's work were not well developed. After the CPR project, I observed a dramatic change in Frank's conceptions of the *sociological* NOS, which dominated his portrayal of science in the post-interview.

A minor difference visible between Frank's pre and post definitions of science is essential to mention here, because it provides evidence of how Frank changed his understanding of science. In the pre-interview, Frank defined science as "exploring the unknown, trying to categorize, trying to put structures the things that are seem random or the things that we don't understand." In the post-interview, he stated a definition of science as "how we go about exploring things that we don't understand in Nature and around us." In contrast to the pre-definition of science, in the post-definition, "how we go about" represents "an" understanding of science where science was perceived one of many views of viewing the world.

In the post-interview, Frank explained his perspective on the social aspects of science more explicitly than he did in the pre-interview. Even though, in the beginning of the post-interview session, Frank defined science as "understanding, explaining, and applying," he further enriched this definition by adding the *sociological* NOS.

Frank had more experience in scientific research in settings other than conventional classrooms compared to the other four participants in this study. He seldom referred to the "peer review" aspect of science and occasionally explained the *sociological* NOS in his portrayal of science in the pre-interview. In the post-interview, he often crafted science as socially constructed, explaining the *sociological* NOS.

In the pre-interview, Frank articulated that scientists check each other's work in order to increase the objectivity of the knowledge represented in these works (Figure 5.1). After the CPR project, he did not argue similarly. He said, scientists review each other, not because they wish to increase the objectivity of knowledge represented in these works, but rather to verify the validity of the works described and to validate the knowledge represented (Figure 5.2).

In the post-interview, Frank, in a comment that was not in response to any of my questions, pointed out the public's view of science, critiquing the public for accepting scientific claims without critically evaluating them. Frank told me that even though a scientific article is published in a scientific journal, it should not be assumed that everything in the article is valid and even consistent with the current scientific paradigm. He proposed that science teachers were responsible for teaching how to critically analyze scientific claims that are presented not only in scientific journals but also in mass media. He also proposed that when scientists come up with a new claim, knowledge, or fact, they should describe who did the research, under what conditions it was performed, and what biases existed. These suggestions are promising in the sense that Frank became more aware of the influences of the collectivization of science (Ziman, 1983) and he developed a more consistent understanding of the *sociological* NOS after the CPR project was completed.

5.2.2.6 Frank's Experiences with the CPR Project

Post-interview findings revealed that Frank found the original research aspect of the CPR project unique and exciting. Frank enjoyed working in groups and collaborating with his peers in their toxicology experiment. Frank was not satisfied with the reviews of his original report; he thought others' comments were superficial and not detailed enough to help him improve the quality of his final published report. Even though, he made changes to his report based on reviewers' comments, he was not certain if the changes were necessary. Frank reported that he would be using a similar peer review system with his students when he starts teaching.

In what follows, I describe Frank's experiences with the CPR project illustrating his responses in the post-interview. The instrument I used to explore Frank's experiences (Semi-structured CPR Interview Protocol) is presented in Appendix C.

Frank mostly liked the collaborative and the original research aspects of the CPR project. In the interview, he told me that working in pairs was productive because two people with different backgrounds had a chance to learn from each other through their collaboration.

> I thought it was neat working in groups. We got into pairs to work on the project. My background is in biology, and the guy that I match up with was in engineering. So it was just neat working together and I actually felt it was useful explaining a little bit about what we were doing, because we had never done anything like it. So it was neat to work in groups. I like to work with somebody else. It was just a neat experience.

According to Frank, the original research facet of the CPR project was unique and it generated enthusiasm. In the project, like the other groups, Frank's group came up with their research question and prior to their investigations, neither the instructor nor the students knew about the probable results. Frank found this aspect of the project exciting. He said:

> I think one aspect of it that I liked was the fact that, okay, when you are in a typical laboratory, if you are working through something with an answer -you know that teacher has the answer, and you are trying to find the answer. But in this case [the CPR project] you are actually doing something that's, I mean, we actually did an experiment on this greenhouse solvent and solute they spray on a greenhouse to shade it in the summer so it doesn't get too hot. They spread it with the solvent to clean it off. So I doubt if anyone mixed the two of them and got a bioassay on it. So it was unique, and I guess it generated more enthusiasm than doing simple recipe work. Dr. Carlsen was working with us through this, and we were trying to get the answer together -so that was another aspect of that I like.

Frank reported his concern about the reviewers' lack of interest and the time spent in providing constructive feedback. He told me that even though two of the reviews he received were fair, the feedback provided did not thoroughly explain the underlying reason for the low ratings. Frank said:

> Both of mine [Frank's reviewers] said "fair," meaning like in the middle. So what I thought was, okay, I agree. You know, no one else looked at this report before. I just typed it up, and I am sure I had typos in it. You know, nobody is perfect. So I went down [to read the reviewers' comments] and there wasn't really that much input. So that's why I have a problem with the overall rating of these things. If you are going to give me that [assessment] then, you know, you've got to give me some explanations why it's so.
>
> It [A reviewer's written comment] was kind of minimum and hurried. You can tell that the person just wanted to get it done. So I think this is major, major flow of the peer review process in this case. I mean we went through this lab and I think it was really a neat lab, you know the design, and there is no answer. You are trying, truly, really find something new and go through this whole scientific process that seems pretty genuine. And all of a sudden it turns into not being so much science because people are not taking the time. You know, they just want to get it done. This is the part where they can get it out of the way. So I have no idea how you -I don't know.

The above statements reveal that Frank was excited about the scientific investigation he conducted in the CPR project and he was looking for a detailed feedback about his report. Nevertheless, he expressed his disappointment that the feedback was not a thorough one and it was not something he was expecting.

In the on-line final student questionnaire (see Appendix F), Frank reported that he did not receive useful peer review comments about his own report. Frank scored 1 out of 5, indicating that he did not receive useful peer review comments. Frank responded “neutral” when he was asked to score on the fairness of the quantitative scores he received from peer reviewers. Frank’s responses to the final student questionnaire also reveal that he was not completely satisfied with the quality and the specificity of the reviews he received.

In the interview, Frank reported that the original research aspect was the most unique characteristic of the CPR project. He discussed the enthusiasm the CPR project generated because of its original research aspect. Frank said:

> I liked this [the CPR project] because of two reasons; if you are going to be in a laboratory situation where the students have the opportunity to do inquiry, to learn, and there is a protocol you have to follow, you can’t just go off and break the protocol and do it. You have to learn how to follow the techniques used so the data can be compared to other groups, but at the same time you have a lot opportunity to come up with your own thing, like what you really want to test. Like I said, the enthusiasm thing - that you are not doing something that has been done for two hundred years, and everybody knows the answer so there is nothing new about it. So that’s what I liked about it. That's why I thought it was different.

Frank was interested in using a similar peer review system with his students when he begins teaching. He explained that a peer review system functions best when students engage in projects that are open-ended.

> I will try it [a similar peer review system]. It probably depends on what kind of project they [the students] are doing. If they are just going to peer review, and everyone is doing the same thing and trying to get the same answer, then the peer review is not really interesting in that case. But if you are coming up with real data and it could potentially mean something that there is no answer for, then peer review is much more important. Somebody might question what you are doing, and I guess I would [use a peer review system], if it was open to the answers and questions.

In the above excerpt, Frank points out that peer review makes more sense when the findings are open-ended and are not the same across the groups. He also mentions that asking students to come up with their research question is crucial particularly when a peer review system is utilized.

In the final student questionnaire (Appendix F), Frank responded positive that meaningful peer review was a reasonable expectation for college students as well as for high school students. Frank's quantitative response of 4 out of 5 to the item, "If I taught science, I would like to use some type of formal student peer review" reveals that he was willing to use a similar system when he begins teaching.

Frank did not learn important things from others' evaluations of his work. He told me that after reviewing others' evaluations, he only changed a tiny detail. The advice Frank received was about the use of first person included in Frank's original report. Reviewers suggested Frank use passive voice rather than active voice in writing a scientific report. Frank did change his original report based on the suggestions reviewers provided. He said:

> I did change my original report. I did one piece of advice, which was you shouldn't put your report in the first person; it should be third person.
>
> So I went back and, for example, in the procedure I said, "I placed the seeds on the thing." I changed my report to say, "The seeds were placed on the thing.", Rather than using I or we, I took that out so I guess in the end it was more objective. We weren't the subject and the experiment became the object.

Frank thought, the quality of his report did not improve after the peer review. He did make changes to his original report, but these changes did not improve the quality of his report.

> Well according to this person [a reviewer], who didn't want me to write 'me' or 'I' or 'we' there, and that's all I really changed. There were other things that were wrong that I changed so they said my report was fair, but they didn't tell me what I could have done to improve it. So I didn't feel like they really helped me to improve.

In the final questionnaire, for the item number eight: "I changed my mind about something in my report because of comments I received through peer review," Frank scored 4, indicating that he agreed with that item. This datum also reveals that Frank did change his mind because of the comments.

Frank told me that he would not have made the revisions he did, if his on-line published report had not been reviewed by someone else, but he was asked to revise it later in the semester without incorporating that feedback.

Frank was neutral regarding his reviewers' comment: he neither agreed nor disagreed with the recommendations, but rather found the comments insufficient and superficial.

> I don't know... I am not a picky person. Like when I saw the reports, when I review other reports, I was thinking more in terms of, if I want to reproduce this exact experiment, what do I need to do? What are these people leading out? And then in the end I was looking for what are their reasoning was. What evidence supports what they are saying? Whereas this person [a reviewer] was looking at my grammar. I guess it's probably good, but some science literature is so dry anyway. I guess I don't know.

Frank was not sure whether it was convenient or not to include the first person as a subject in a scientific report.

Frank suggested making the authors aware of who the reviewers were. According to Frank, this would prompt reviewer to provide more constructive feedback.

> I am sure it happens, but I think when someone is going to put their name on it, like if someone is reviewing an article before it is published and if you put your name on that, you are putting your career on the line. What is this kid is going to do? He is going to type a few notes and hit enter and that's the end of it. They don't necessarily have any investment in this project so that's probably an inherent flaw that you are going to find in peer review, college peer review classes I mean. How you are going to make them continue to carryout the whole scientific process?

Frank reported that he was neutral (scored 3 out of 5) with the item that "it is easier to say what I really think when I don't have to sign my name or meet in person with the students who wrote the research reports" (Appendix F). This finding implies that Frank was not an advocate of anonymous peer review.

5.2.3 Case 2: Cindy

5.2.3.1 Demographic Information

Cindy, a pseudonym, was a Science Education student majoring in Biological Science. In the pre-interview, Cindy told me that she would be interested in teaching anything from biology to microbiology after the graduation. She was expecting to graduate in 2004. After the graduation, her plan was to pursue a Master of Science degree in Biology. Cindy did not participate in a systematic scientific investigation in a setting other than a conventional college class prior to the CPR project. At the pre-interview, Cindy mentioned that she loves teaching kids.

5.2.3.2 Cindy's Conceptions of the NOS before the Activities of the CPR Project (Pre-interview Findings)

In the pre-interview, Cindy reported that science was *empirical, subjective, tentative, value-laden* and a *human endeavor*. She implied that science had social aspects and it was a *human endeavor*. Cindy's pre-conceptions of the NOS are described below and summarized in Figure 5.3, at the end of this section.

Cindy described science as not being always progressive and completely objective, but "full of surprises." She agreed that science was *tentative* and an "ongoing process" (Figure 5.3). However, this ongoing process was not progressive in the sense that it would reach a point that explains everything. Cindy explicitly mentioned that scientific theories were always falsiable. She stated her definition of science as follows.

> Science is more of an exploration of our unexplained world. I don't think we can ever reach a point that we can explain everything, so science is kind of ongoing. We have to be creative. I think it's very subjective. We can't believe everything we hear, no matter who tells it to us. And it's exciting - you will never know what science is going to bring you.

I observed a discrepancy in Cindy's definition of science when she described science in contrast to other disciplines. During the interview, on one occasion, Cindy told me that science was different from other fields of inquiry because, science uses proof whereas other studies do not. On another occasion, she stated that one cannot prove anything in science. I had a feeling that Cindy read about Popper's explanation of falsity (Popper, 1959) and was describing the falsifiability of scientific theories in her definition of science. Below, reader may recognize the same notion of falsifiability Cindy discussed.

> In philosophy, we are not really trying to prove anything [like science]. Well, you never prove anything in science, but you are not proving anything in philosophy, I have never taken any philosophy class, so in science it's more that we are not sure whether it's right or wrong.

In the pre-interview, Cindy defined science as "a technical investigation" whereas religion and arts were not. She explained the *empirical* characteristics of science as including observation and scientific logic (Figure 5.3).

Cindy responded that scientific facts would not exist if humans did not exist in the world. The same was also valid for the non-scientific facts. The following comment illustrates her view.

> I don't think it [existence of scientific facts] really matters, because that's [scientific facts] just the way we explain things. So there are theories in philosophy, and they will be useless, because there will be no one to believe in.

According to Cindy, scientists determine whether other scientists' scientific claims are true or not by testing again and again. Unless scientists disprove the proposed claims, these claims will be considered valid scientific explanations. She maintained:

> They [scientists] just test it [other scientists' claims] over and over. They will try to disprove it.

In the above statement, Cindy once again implies the falsifiability characteristic of scientific claims as this concept was described by Popper (1959). Through the interview, she referred to the same idea, as illustrated in the following.

> They [scientists] do, or arrive at a conclusion then other scientists try to disprove it. And that is good, because there are a lot of chances of bias. You can't ever prove anything that is absolutely true. You can only disprove things.

I asked Cindy whether she had read Popper's work. She responded positive as what follows.

> Yes [I read], so science is kind of ongoing thing. I think we are always going to find things that are going to be disproven; things that we don't see gets disproven in a life time.

After Cindy told me that she read Popper and perhaps some other science philosophers' work, I asked more specific questions. Cindy's responses were interesting. At first, she responded that science was *value-laden*. Later, she told me that science was more innovative and value-free as opposed to society, which is often conservative. She said:

> Yes, I think it's [science] different [than other fields], I don't think science has - I think it has values but not as much as the general public has. It [science] is trying to break values, you know, they are trying to go beyond what people think is right, sometimes to come up with new technology.

In regards to values in science, Cindy's responses were similar to those of the other participants. She mentioned that scientists' cultural backgrounds and personal worldviews influence the planning and the design stages of a scientific investigation.

> I guess it [the influence of human values on scientific claims] depends on the person and the morals. But yes, I think if a scientist doesn't believe in cloning, I don't think *she* will do it, but if the scientists think it's good, they will do it. So morals do have an affect. *[Italic changed]*

Cindy mentioned that science was a *human endeavor* because people practice science (Figure 5.3). According to Cindy, in scientific practice, scientists compare and contrast their results with one another and with the public.

> Like I said, scientists are always comparing. They are always talking about what they have. They communicate their results with public. That's very social. Then they write it about it. That's social.

Cindy's perception of the social characteristics of science did not thoroughly address the *sociological* NOS. Cindy expressed that science had social aspects merely because it was practiced by people and through communication (Figure 5.3). This perspective does not necessarily include the *sociological* characteristics of science, which advocates that scientific claims are socially constructed but not objectively discovered.

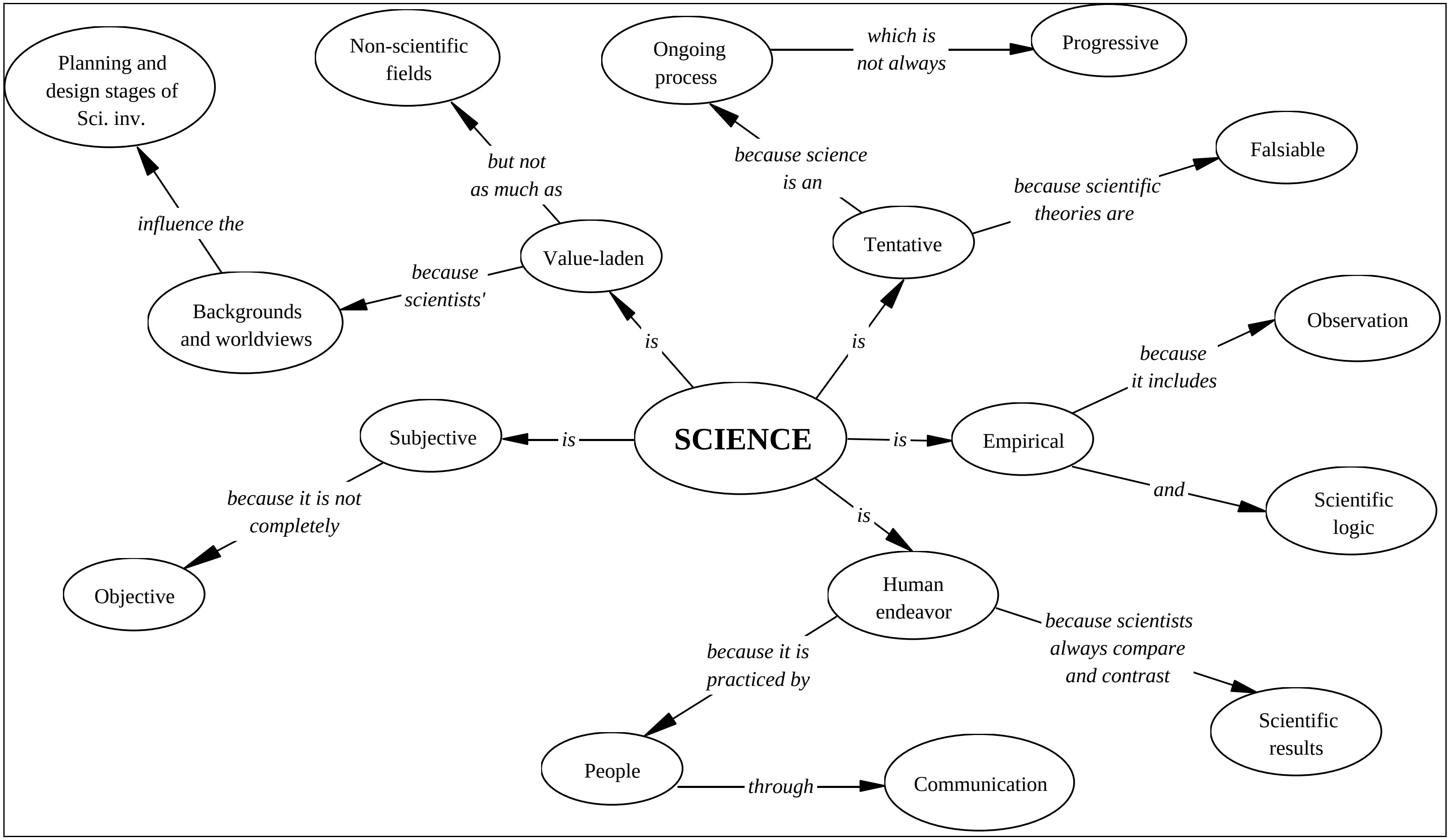

Figure **5.3**: Cindy's Pre-conceptions of the Nature of Science.

5.2.3.3 Cindy's Conceptions of the NOS after the Activities of the CPR Project (Post-interview Findings)

After activities of the CPR project were completed, Cindy defined science in reference to its *empirical*, *subjective, tentative*, *value-laden, human-endeavor* and *sociological* characteristics. She discussed the *value-laden* and the *human endeavor* characteristics of science in reference to the *sociological* NOS. Cindy' post-conceptions of the NOS are described below and summarized in Figure 5.4**,** at the end of this section.

In the post-interview, Cindy defined science as follows:

> Science is the exploration of our world. There are philosophical ways of to explaining it, and there are also ways where we just experiment with things to learn more about our surroundings.

In the above definition, Cindy implied the role of experimenting in science.

Cindy explained the tentativeness of scientific claims in reference to the concept of falsifiability. She said:

> Okay, so we are just kind of a little fluke in the entire universe, right? There are a lot of things we don't know about, and there are a lot of things that we think right. Then sometimes these things are proven wrong and it's not what we are expecting. So who knows how long we are going to be here? Who knows what things are going to go away that we don't think would; things, you know, things that we wouldn't expect? But they happen so that's why I think that nothing can be proven. It [scientific claims] can be tested over and over again, and they can come up the same way each time. We use them to benefit us, but they can, maybe some day, be disproved.

Cindy told me that science, religion, and philosophy had similar characteristics. Her argument was that, no matter the paradigm one has engaged in, be it scientific or non-scientific, one chooses to believe in something. For instance, she articulated, all scientists work from the belief that the universe is real. Likewise, religion has its own beliefs. Another example of how science and religion are similar is that, there are scientists, who have common beliefs, and there are scientists, who have different beliefs; likewise, there are people who believe in the same or in different religions. The excerpts below reflect her thoughts.

> **Cindy:** I think, actually science and philosophy and religion are pretty close.
>
> **Interviewer:** Why?
>
> **Cindy:** They are related, in terms of a belief. We believe this will happen. We believe in a God, or we believe that we are in a universe - all that kind of stuff. It's similar I guess.
>
> **Interviewer:** So in science do we have some similarities?
>
> **Cindy:** Beliefs of different braches of science. There are different branches of religions. I think they are all trying to accomplish the same thing, just to try to figure out, you know, what's going on.
>
> **Interviewer:** So what about the facts or explanations within a paradigm and validity of these explanations within this paradigm?
>
> **Cindy:** Well, like sometimes I think that, for example, our religions - there are so many different kind of religions and they all have their own little thing that people believe. Maybe that's just a way to make them to feel comfortable with their lives; maybe, you know, help them to get through things. So scientist kind of have these beliefs, like, you know, this always happen. This seems to always happen. So we are going to believe that if we do this, this is going to happen. We feel comfortable with that and we can build things from that.

Cindy considered the belief in the existence and in the harmony of the universe similar to the other beliefs in non-scientific paradigms. In that manner, in religion, one might choose to believe in God, and similar to that, in science, one might choose to believe in the physical existence of the universe.

Cindy mentioned that in order to decide on the validity of the scientific claims, scientists share their results with the public. Someone might argue about your results, criticize your findings, and sometimes try to disprove your conclusions. Cindy said:

> If you make a statement about something you are experimenting on, you share your results with the public. There are always going to be people that are going to say “Oh, I don’t believe this guy I am going to go look it up by my own, and maybe do some research.” There are always going to be people doing that; comparing, sharing, criticizing.

Cindy mentioned, “collaboration and communication is really important” to determine the validity of scientific claims (Figure 5.4). She pointed out that peer review was crucial in validating scientific claims. She explained as follows:

> If you have one person that is working – ah, that’s probably why teachers use group projects. I mean it’s good to have a lot of people with different ideas. That way it's like estimation. You are going to arrive at a better answer if you have many different things to chose from unless instead of only one.

Cindy responded that scientific facts were *tentative* because the physical existence of the universe was changing (Figure 5.4). She did not mention that scientific facts were subject to change because new theories and claims were proposed. Rather, she stated that scientific facts were changing because the parameters relevant to these facts were changing. She illustrated “gravity” as a scientific fact and explained that gravity would change when the planets and the relevant conditions change. She stated:

> Definitely [our conceptions of gravity may change]. I am taking an astronomy course right now. Maybe that’s why all the planets together have this specific gravity right now. So say one planet exploded, or something that would throw out our gravity, or gravity. Then maybe the pen wouldn’t fall as quickly or wouldn’t fall right there. I mean there is always something like that could happen.

Cindy asserted evidence that facts (or beliefs in the existence of facts) in other disciplines were also subject to change, similar to the scientific paradigm.

> Yeah, say for instance, okay Roman Catholic churches where I used to go when I was younger, they never believed in contraception. Now they do. I mean, it used to be against their beliefs to do that but now they think it's okay. This shows that maybe this is a good thing. So in that way their beliefs have changed.

Cindy maintained that science was not completely objective, stating:

> I I don't think science is objective. We don't know everything. There is always going to be something that messes up. There is always be something subjective. Things don't always go the way you expect them to go. And scientists aren't all knowing. I mean, they are just humans like everyone else, so they are going to make mistakes like everyone else. There is an element of bias in their experiments. They may not want to, but there is always going to be something they believe that happened because of a certain reason. And then it does happen, but it happened for a different reason. They are going to believe that it happened because of this. So I mean, you always have to take this into consideration whenever people share their results. You always have to keep on trying to disprove it or make it better

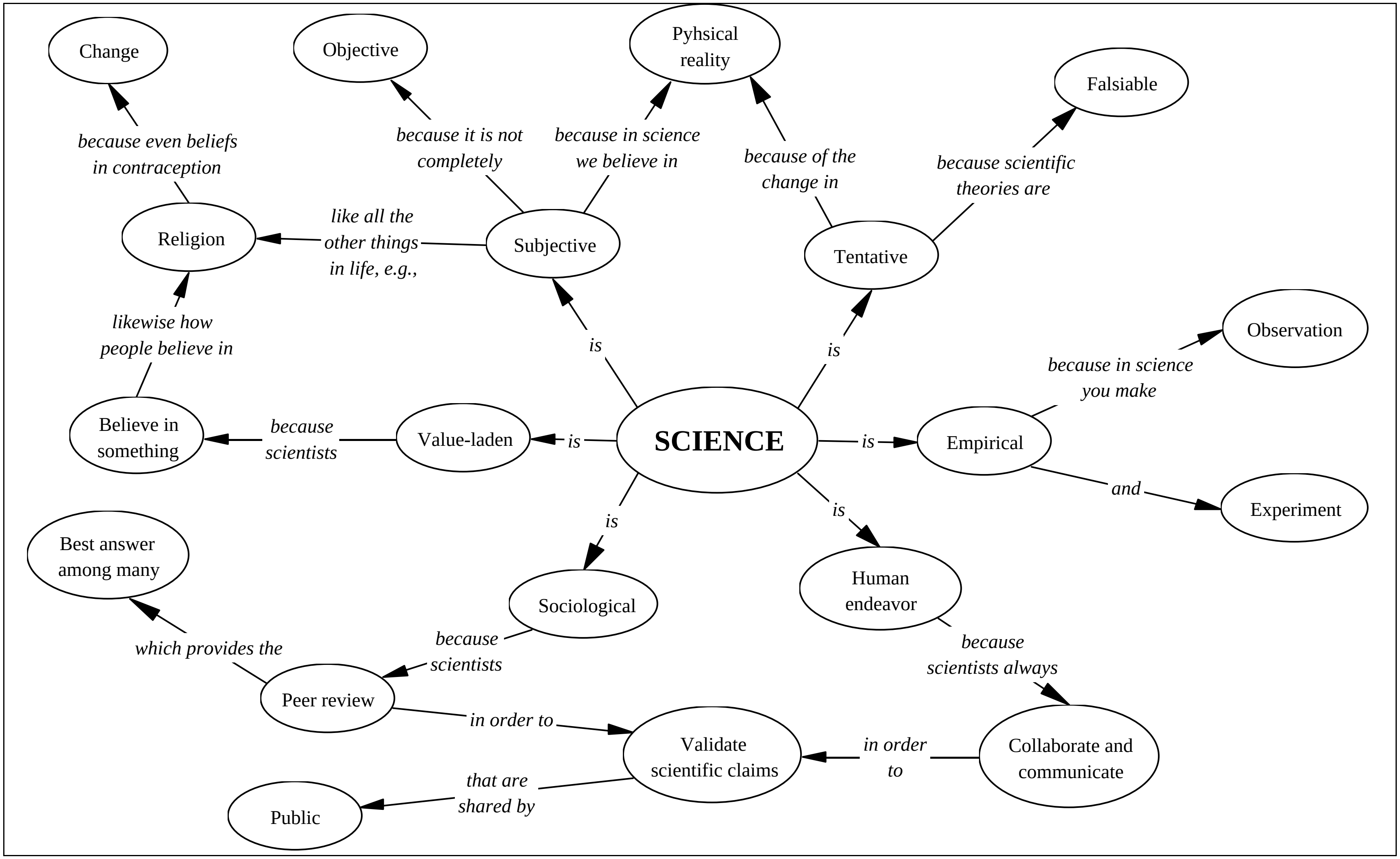

Figure **5.4**: Cindy's Post-conceptions of the Nature of Science.

5.2.3.4 Triangulation of the Interview Findings

In this section, I attempt to validate my pre-interview and post-interview findings using Cindy's written responses to the philosophy of science questionnaire administered before and after the CPR project. This section comprises two parts. In the first part, I compare Cindy's pre-conceptions of the NOS with her written responses to the pre-questionnaire, and in the second part, I compare her post-conceptions with her post-responses.

Part I

The propositions I compared in this part are about how Cindy (a) explained the *tentative* characteristic of science, and (b) distinguished science from other disciplines of inquiry.

In the pre administration of the questionnaire, Cindy defined science as:

> Science is the study of nature where new ideas are tested to death in order to gain enough knowledge that can be explained to others. This idea can then be scrutinized and questioned by anyone in order to better refine it. Hopefully the idea will act in order to better society.

In the above statements, Cindy expresses that science is *tentative* and scientific theories are falsiable. In the pre-interview, she also pointed out the *tentative* characteristic of science, describing how science is an "ongoing process" and how scientific claims are falsiable (Figure 5.3). In the pre-interview, Cindy told me that even though science is an ongoing process, it is not always progressive. In the pre-questionnaire, she did not comment on the progressive nature of science, but rather wrote that the ultimate objective of science was to improve society.

In the pre-questionnaire, Cindy distinguished science from other fields of inquiry:

> Although it is just as creative and colorful, science aims to develop into fact. It is the art of solving problems of the world and making it a better and more efficient place. It is not fact unless it can be seen and proven time and time again.

In the pre-interview, Cindy frequently expressed that scientific facts could never be proven, specifically referring to Popper's falsification idea in her explanations (Figure 5.3). However, in the pre-questionnaire, she implied that facts could exist when they were "proven time and time again." Perhaps the reason her portrayals of scientific facts differed is that she was explaining a perception of science similar to that of Popper. She might have chosen to express science philosophers' definitions (e.g., Popper's) rather than her own conceptualization.

To another item in the pre-questionnaire, Cindy wrote:

> Yes. I believe problem solving is more accurate when there are more than one person contributing different ideas and discussing them. Art and English are more opinionated. One person might call a few red circles on a canvas art, someone else may not. Either way, both are right. Science group work inside the classroom should not be to only arrive at a right answer. Students should learn to listen to other's opinions and discuss the pros and cons of an idea. Helping each other out and collaborating. Outside a classroom, scientific data is criticized and picked apart. People try to disprove each other sometimes just to get recognized.

Cindy's responses are blurred in the sense that I could not find meaningful connections regarding the NOS tenets. In regards to group work, my interpretation of her understanding is that she thinks group work should not only seek to find the correct answer, but also encourage students to listen to each other and respect their opinions.

Part II

The propositions I compare in this second part are about how Cindy (a) defined science in reference to its *empirical* characteristic, (b) pointed out the role of scientists and science in society, and (c) discussed the essence of collaboration and communication in scientific enterprise, in the post-questionnaire and the post-interview.

In the post administration of the philosophy of science questionnaire, Cindy defined science as:

> Science is a tool to used to explore our natural world. It is the observation and study of our environment to gain knowledge about or to better it.

In the above definition, Cindy mentions the role of observation in science. She describes science as a tool to explore Nature. In the post-interview, Cindy defined science by addressing the *empirical* characteristics of science and pointing out the role of observation and experimenting (Figure 5.4).

In the post-questionnaire, Cindy wrote:

> Scientists and the scientific community are seen as authoritative and usually highly respected members of society. Science is the process behind creating technology, medicine, and understanding of our natural environment. Without these things, functioning as a modern society would be impossible.

In the above text, Cindy views science as the backbone of modern societies. The influences of scientific claims are pointed out, and scientists are considered highly respected people. Cindy did not discuss how scientists were respected by the society in the post-interview. She only pointed out that scientists did peer review in order to come up with the best answer (Figure 5.4).

In the post-interview, Cindy explained science as a *human endeavor* because scientists often collaborate to validate scientific claims (Figure 5.4). She also mentioned the *sociological* NOS by describing how scientists use peer review to validate the scientific claims. In the post-questionnaire, she mentioned the role of collaboration in science as being crucial to reducing the bias. She wrote:

> I think communication is important in all fields, however art and English can be done without worry of bias. Critiques and further studies that may prove another study wrong are ways that scientists display the social aspects of science. The competitive aspect would be less common, I would think, in a science classroom. The students are working collaboratively and helping each other to reach a desired outcome. I don't think this is a problem in that it is unrealistic to what science is really like. An important part of research is working collaboratively. The competitive aspect may come through science fairs or later on in their own.

The ideas developed in this section do not thoroughly addressing Cindy's understanding of the NOS. I discuss this issue in the conclusion chapter, and make suggestions for future research to utilize other triangulation methods.

5.2.3.5 Changes in Cindy's Conceptions of the NOS

Cindy did not dramatically change her conceptions of the NOS regarding the *empirical, subjective, tentative, human endeavor* and *value-laden* characteristics of science after the activities of the CPR project were completed. Cindy significantly improved her understanding of the *sociologica*l NOS as is evident in her post-responses.

In the pre-interview, Cindy implied that science had social aspects and it was a *human endeavor*, but she did not provide evidence to support her arguments. After the CPR project was completed, she addressed those same characteristics of science, but this time by providing evidence in reference to the *sociological* NOS. She explained that science was a *human endeavor* because scientists always collaborate and communicate with each other to validate scientific claims. In this portrayal of science, Cindy implies that scientific claims are not absolute and a static body of knowledge that is found in Nature for humans to discover. According to Cindy, peer review in science is a process of systematically choosing the best working answer among many others. She also added that even though scientists choose the best answer by reviewing one another's work, the public is the authority which decides on whether to accept that best answer. With the mutual acceptance of the public and the scientific community, some of those best answers (scientific claims) become scientific facts, which are mostly accepted as the true explanations of a scientific phenomenon.

In the post-interview, Cindy explained why science was *subjective* in a way that differed from her explanations in the pre-interview. She often referred to the falsiability of scientific claims during the pre-interview. In the post-interview, she mentioned falsiability once, but she also told me that science was as *subjective* as other fields of inquiry, for instance religion. She argued that nowadays the Catholic Church was more likely to accept contraception which was rejected previously. This shift in attitude does not differ from how scientists change their scientific arguments or explanations of a physical phenomenon.

In the post-interview, Cindy did not argue that science was less *value-laden* than non-scientific fields as she had argued in the pre-interview.

5.2.3.6 Cindy's Experiences with the CPR Project

Cindy particularly liked the peer review aspect of the project and said it was unique. However, she wished that her peers' evaluation of her work would have been more detailed. Cindy agreed with her peers' evaluation of her original report, made the suggested revisions, and found them helpful, adding that she would have liked the opportunity to speak with the reviewers. Cindy was interested in using a similar system with her students when she begins teaching.

In the next paragraphs, I explain Cindy's experiences with the CPR project by providing excerpts from the interview. The instrument (Semi-structured CPR Interview Protocol) I used to explore Cindy's experiences is presented in Appendix C. I also report some of Cindy's quantitative responses to the final student questionnaire (see Appendix F for the questionnaire items).

Cindy liked the peer review aspect of the project and the opportunities it provided students for improving their work. In the interview, she said:

> I liked the students can read it [each other's report] and tell you what you did wrong. I liked that a lot.

Cindy reported concern about the credibility of the reviewers' feedback, also noting that she found her reviews incomplete.

> I didn't like, for example, the person read mine [Cindy's original report] - I wasn't sure how well they did on other lab reports before then. I heard a lot of people saying, "That kid is full of, you know, because that was a good paper." They didn't write any credit. They read it very poorly. So depending on the readers, I guess credibility or how much his or her experience of reviewing our report is what grade you got I think.

Cindy reported that she agreed with her peers' evaluation of her original report. She found the suggestions helpful and made changes based on the recommendations.

> I think the results were, actually there was a mistake in mine. I think I misspelled couple of words. So, yes [I agreed with peers' evaluation]. That was helpful.
>
> I did [the recommended chances]. I looked over at least one more time more carefully and make sure everything was all right and matched up. And then there was the discussion part.
>
> The only one that was helpful was one where I made really embarrassing mistake. I spelled serial dilution like "cereal," like the food cereal. If that was going to be published, I would feel like an idiot. But one person said that the results didn't match up with discussions. I went over and looked at little harder and I did make a change there. So that was helpful.

In the final student questionnaire, Cindy scored 4 out of 5, indicating that she agreed with the questionnaire items "I received useful peer review comments about my own report" and "the quantitative scores I received from peer review were fair" (Appendix F).

Cindy told me that she was unlikely to make the similar changes, if her report had not been reviewed but she was asked to revise it by herself. She said:

> Honestly, probably not. If I count the grammatical stuff, maybe not. If you have a peer review, people can tell you, it doesn't sound right. Sometimes when you are writing it, or say it loud or someone else tells it to you, you don't realize what you have done. So that was pretty helpful, but sometimes I think the peer reviewer veered toward a certain style and maybe you don't agree with that, They may think it's right, even though you may think yours is better. So that might be a problem too. Overall I think it was good.

In the final student questionnaire, Cindy strongly agreed with the item "I changed my mind about something in my report because of the comments I received through peer reviewed."

Cindy reported having previous experiences with the peer review, but these were neither on-line nor anonymous as was the CPR project.

> I think the only other time I had peer review was on paper. This [the CPR project] was on-line, and that is pretty different.
>
> In my labs, even my English lab, they [Cindy's previous peer review experiences] just took your paper and wrote on it or made some corrections. This project [the CPR project] was different because you couldn't see your peer reviewer. You didn't know who did it, so you couldn't talk to them about it. They just wrote, "I thought you were trying to say this, but I am not sure…" You know, you couldn't just meet up with them and talk to them to say "No, I actually meant this." So that was different.

In the above excerpt, Cindy points out that, because the review system in the project was anonymous, students did not have the opportunity to go back to reviewers and ask them to explain their feedback in detail. On the other hand, Cindy scored 4 out of 5, to the final questionnaire item; "it is easier to say what I really think when I don't have to sign my name or meet in person with the students who wrote the research reports," indicating her agreement with this statement.

Cindy, who as mentioned, would use a similar peer review system with her own students, stated that it would help students understand the social aspects of science.

> Yes, at least once just to see how it works. I think that would be a good way to introduce the social aspect of science. I think that would be good.

In the final student questionnaire, Cindy reported her strong agreement (scored 5 out of 5) that meaningful peer review was a reasonable expectation for college as well as for high school students. She also scored 5 out of 5, for the item; "If I taught science, I would like to use some type of formal student peer review" indicating her willingness to use a peer review system when she begins teaching (Appendix F).

Cindy thought it would be better if they had chance to run the tests more than once. She said:

> Maybe we could do three-part experiment where we looked at it that then did another one and compare the two. For example, maybe compare a grown up plant with leaves - maybe put the chemical on it and see how it compares with the germinated ones. The ones that are already grown are probably going to be harder than the ones that aren't germinated yet. So just to compare to something like that.

Cindy is concerned about students' grading one another's work. She suggested anonymous peer reviews for the college levels but not for the K-12 levels.

> I think, it's good that it is anonymous, but the fact that it's going to be students with the same experience grading each other, I don't know if they take it seriously. You know, do they really read it over carefully and make their best suggestions? I think it will be good, but students are different. I think that would be good for more college level students, actually, to have peer reviews like the anonymous ones.

Cindy learned from others' review of her original report, but she suggested that it would have been more helpful, if she had a chance to talk to the reviewers.

> Yes, I did, but I think, I could have learned more if I could have talked to them. Maybe I could have asked them how they set up a lab like that. I could ask how they set up the wording, what they would keep out, what they would add - because I thought, mine was kind of wordy compared to ones that I have read.

Cindy responded that her final published report was more effective than her original report.

In the final student questionnaire (Appendix F), Cindy also reported her strong agreement that "peer reviewing other students has helped her to improve her own scientific writing" (scored 5 out of 5). She agreed, "peer reviewing other students has helped her to think more critically" (scored 4 out of 5).

5.2.4 Case 3: Jacob

5.2.4.1 Jacob's Demographic Information

Jacob, a pseudonym, was an undergraduate student majoring in Earth and Space Science- Secondary Education. At the time I interviewed Jacob, he was also pursuing his environmental education certificate. His expected graduate date was in 2004.

Jacob reported that he had two scientific research experiences in settings other than a conventional college class although, his research experiences were not similar to Frank's experiences. Jacob was participating in research in order to learn about scientific knowledge and its method, rather than because of career interest. In one of his research experiences, Jacob studied the effects of European corn bore on corn. This entomology research, which lasted for an entire summer session, was conducted both in a farm and a lab. In his other research experience, Jacob studied the methane composition in ice cores. Jacob was participating in this research, which was partially conducted in labs and lasted five months, at the time that he was first interviewed.

5.2.4.2 Jacob's Conceptions of the NOS before the Activities of the CPR Project (Pre-interview Findings)

In the pre-interview, Jacob described science *as empirical, subjective, value-laden,* and a *human endeavor*. He did not mention the *sociological* NOS in his portrayal of science. Jacob's pre-conceptions of the NOS are described below and summarized in Figure 5.5, at the end of this section.

Before the CPR project was started, Jacob addressed science with respect to its *empirical* and theory-laden characteristics. He pointed out the logical reasoning followed in scientific methods and the role of testing in verifying scientific claims (Figure 5.5). In the pre-interview, Jacob stated "science [is] a logical way, a way in which to find out more about something using logic and testing."

Jacob emphasized the theory-laden characteristic of science in his first definition of science, stating:

> Science is a lot of theories and hypothesis that are based on our logic. It just doesn't come from anywhere. We have to think how to test it or think how something works in order to test it. I think that's a big part of science, testing what you might think - why that's happening.

In his definition, Jacob addressed "testing" and "logic" as being the two major characteristics of science that differentiate science from other disciplines of inquiry. He stated that, in philosophy or in astrology, you can test your argument but "you cannot make tangible observation." In science, tangible observations are made, and through logic and testing, these observations are verified. When the scientific claims are "tested again and again," they are accepted by the majority of people; hence these claims become the scientific knowledge.

According to Jacob, science is "supposed to be (objective) but it's not." The reason science cannot be completely objective has to do with human nature: "humans cannot avoid their environment or their past experiences, and you just can't assume it's possible." With this statement, Jacob implies the *value-laden* characteristics of NOS (Figure 5.5).

Jacob articulated that scientists work in groups in order to make scientific claims more objective or to reduce the subjectivity of these claims. The followings reflect Jacob's understanding of why scientists work in groups:

> **Interviewer:** Do you think, even though scientists want to come up with an objective truth as much as they can, but because of their background, they cannot do this? Is this something that is beyond their limitations, or is it within their limitations? Is it an option for them?
>
> **Jacob:** I don't think it's like an option, part of it maybe, I mean, you can work hard against your values, and your beliefs, and your past experiences. It's difficult, but to be objective is not an impossibility for maybe a group of scientists because you are checking, first of all, and you have different past experiences, beliefs, values, and that sort of thing. If the goal of the group is to be objective, you are going to be looking at everyone else's work as to whether or not it is objective. I think it's harder on an individual basis, I do think that it's almost impossible to do.

Jacob did not agree that complete objectivity can be achieved in science. He stated that working in groups is a requirement for decreasing the subjective characteristics of science but this practice will not eliminate it completely (Figure 5.5). My interpretation of Jacob's responses is that he thinks science is *subjective.*

In the pre-interview, Jacob stated that scientific facts "are something that you can observe." He posited that for a claim to be scientific fact, he needed to observe it through his sensory organs, particularly vision.

When I asked Jacob to compare the scientific facts with facts in others paradigms, he explained that the facts in other paradigms were not seen, so he did not consider them facts. He said "I can see the pen falling [referring to Newton's Law of Motion and gravity] but I cannot see the God [in theology], that's the only difference to me I think." When I told him that some people believe that they have seen the God, he responded:

> That's another discussion [some people see the God]. I mean you can test it [pen falls] again, drop it again, and it'll fall again. You know, say you want to test your one god theory, and go looking for other gods, and don't find them. You essentially tested that theory, and you haven't been able to disprove that they are similar in a way, but the basis for it is observable in one situation.

Jacob compared the process of verifying claims (or facts) in science with that of verifying claims (or facts) in other disciplines. In addition, he responded that science was a *human endeavor* because it was a social activity (Figure 5.5). However, he did not provide any evidence to support why he viewed science as a social activity. Indeed, the *sociologica*l NOS was not addressed in any of his explanations in the pre-interview.

Before scientists accept scientific claims made by other scientists, Jacob said, these claims must be "tested many times." He would accept a scientific claim only if the claim makes sense, and if he finds the similar results after running the same experiment. In the following excerpts, Jacob explains his point.

> If it [scientific claim] makes sense, I would accept this, but I would want to test it first.

> When it [a scientific claim] is tested many times, though in different situation, like, for example, a scientists hypothesis that garlic can fight or can prevent some disease, they will be happy when someone does this essentially, proves that they are right. So they [other scientists] need to test it [to accept the scientific claims].

When I asked Jacob "if I were a scientist and proposed a scientific claim in written form, how can this scientific claim be verified or legitimized?", he responded:

> Well it will make sense if it's in accordance with my scientific knowledge. Like you can write on a piece of paper, I have previous knowledge, but I believe in it because it has been tested. Do you know what I mean?

Even though, scientists' previous knowledge was mentioned in the above excerpt, Jacob strongly believed that "being tested" was the only, if not the major, requirement for validating scientific claims (Figure 5.5). Jacob elaborated:

> The best way is just to test it. If you wrote, the pen is going to fall down, like okay, let's see it then, and that is the way it was accepted, or it wasn't accepted.

In the pre-interview, Jacob told me that science was *value-laden*. He said:

> Yes, it [scientists' past experiences, backgrounds, and societal, cultural, and personal beliefs] influences their knowledge or what they think to be true.

Jacob explained that scientists' cultural backgrounds and personal worldviews influence what they study. He noted that the planning and design stages of a scientific investigation are influenced by scientists' understanding of truth and what makes things true. He said:

> If you hypothesize a theory, and it is new, and you know you put a lot of time and effort into it, and towards the end you start to find out that it might not be true - but actually no. Before that you are looking for, what is making it true, not what might be making you wrong or incorrect, that occurs.

Jacob did not address the interpretation and the negotiation stages of scientific knowledge as being influenced by scientists' cultural backgrounds and personal beliefs.

In Jacob's pre-interview analysis, I could not find any indication of Jacob's thoughts about the *tentative* characteristic of scientific claims. This is a limitation of this study; I forgot to ask Jacob interview questions regarding the *tentative* NOS. Because I was not able to identify Jacob's pre-conceptions of the *tentative* NOS, I assume that his conceptions did not change, and if they did, I am unable to report them in this study.

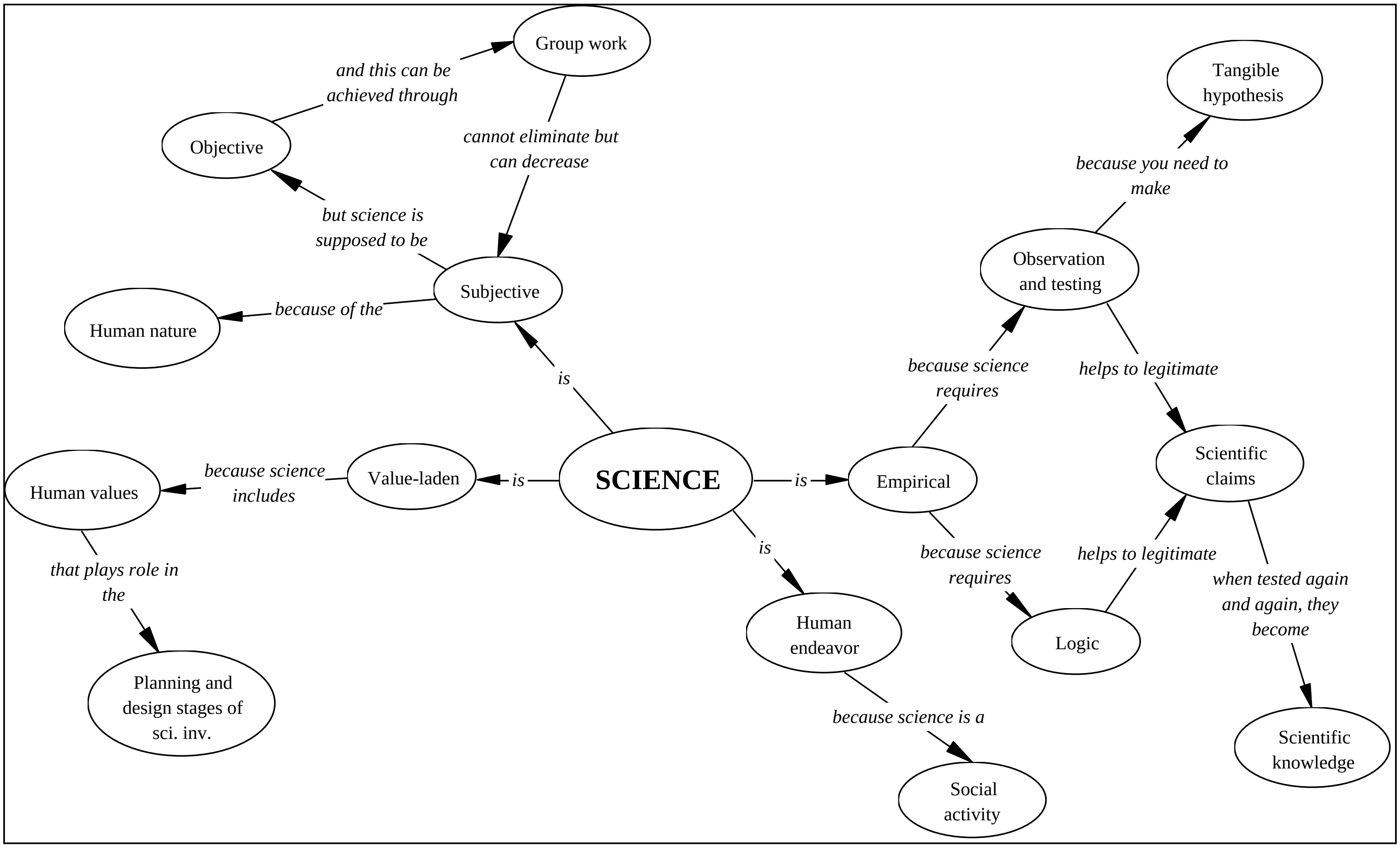

Figure **5.5**: Jacob's Pre-conceptions of the Nature of Science.

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5.2.4.3 Jacob's Conceptions of the NOS after the Activities of the CPR Project (Post-interview Findings)

In the post-interview, Jacob characterized science as *empirical, tentative*, *subjective, value-laden, sociological*, and a *human endeavor*. Jacob often referred to "peer review" and the *sociological* NOS in his explanations to support the *human endeavor, value-laden, subjective*, and *tentative* characteristics of science. Below, I describe Jacob's post-conceptions of the NOS, which are also summarized in Figure 5.6**,** at the end of this section.

Jacob stated, "science is a method of trying to find out how natural things work, how to solve problems, it's based on our observation and experimenting." He made explicit that science was *empirical* and *tentative* (Figure 5.6). He said:

> It (science) is tentative; it is not something that will stay the same forever. What you observe today may not be what you will be observing in the same spot a hundred years from now, or maybe someone else will be observing.

Jacob stated that the main difference between the scientific paradigm and other paradigms is related to the *empirical* characteristics of science. Jacob emphatically stated that science required testing of ideas and observing Nature. He said:

> Science as opposed to theology, or a lot of other fields is based on observation, as opposed to faith, or something like that. Ideas aren't pulled out randomly. They are based on inferences you make about what you observe, or what you try to test or experiment. The role of theories and testing is very important in the field of science, whereas in theology, you can't really test. A lot of ideas can't test how the world - I don't know, I don't want to get in theology, but you know what I mean. Those are the main differences, I think.

In the post-interview, Jacob stated that scientific claims are *tentative* for two reasons (Figure 5.6). The first is that the physical phenomena and their explanations are subject to change. Second is that people's ideas regarding the explanation of the physical phenomena are subject to change.

> Things are changing as far as, for example, our continents are not always going to be in the same place, or they were not always in the same place.

Jacob thought scientific facts are actually the physical existence of the natural phenomena. In that sense, scientific facts are subject to change if the universe changes. For instance, he said:

> Can it (gravitational force as a fact) change? Yes, the Sun is going to develop. There is not going to be any gravity there because there is not going to be any here. Do you know what I mean? Outside in space, gravity is not the same here or it will not exist. Earth will not exist nor will the moon.

In another portion of the post-interview with Jacob, he changed his argument and told me exactly the opposite of what he said before.

> I know in the beginning of the interview I said, like, of course science goes on (referring to the scientific facts), but I just had to rethink it. The natural phenomena will go on, but not the study of Nature.

Jacob was addressing people's ideas when he talked about scientific facts rather than the physical existence of natural phenomena. He told me that scientific facts would change because people's ideas about the physical phenomena were changing. I personally found it difficult to identify Jacob's underlying conceptions regarding the *tentative* characteristics of scientific facts. Therefore, here I report two different explanations provided by Jacob for why scientific claims (knowledge and facts) are *tentative.*

In regards to objectivity in science, Jacob reported that science was “ideally objective but in reality not.” He said, “the goal of science is objectivity.” Yet, he stressed that full objectivity was impossible to be achieved because scientists had values, and it was not possible to eliminate scientists’ values.

Jacob mentioned that scientific knowledge was *value-laden* (Figure 5.6). He said, “What scientists do have moral implications.” Jacob noted, “Society obviously has a role in how scientists do their work and how they decide what to do with their work.” He indicated that human values play a role in the planning and design stages of scientific investigations (Figure 5.5).

“Evidence and data” were considered two important requirements for a scientific argument. Jacob mentioned that people’s background influenced the scientific knowledge generation process. He argued that knowledge generated from anything but evidence and data was bad science. He stated, “Good science is based on evidence and data, bad science based on other things.”

In the post-interview, Jacob explicitly emphasized that after scientists conducted their experiments “they publish their findings.” He stated, “scientists gather all their data and try to be creative and logical and framing it together” before they write their reports. A negotiation of scientific knowledge was seen as occurring when scientists went through peer review. Jacob referred to logic and reasonable data as the means of generating scientific knowledge both in scientific method and in peer review. He stated “the ones [scientific reports] that explains their procedure the best, the ones who have reasonable data” would be published and hopefully be accepted by the scientific community.

Jacob provided evidence of why he thought science included *human-values* in reference to peer review in science. He illustrated an example of how other scientists' values play a role in negotiating scientific knowledge. The following illustrates his argument.

> The people in charge of the magazines, or whatever - the journals, they decide, definitely not the person who wrote it, which publications will be published.

In the post-interview, Jacob portrayed the *sociological* NOS by referring to the peer review, the role of human values, and the interest of society (Figure 5.6).

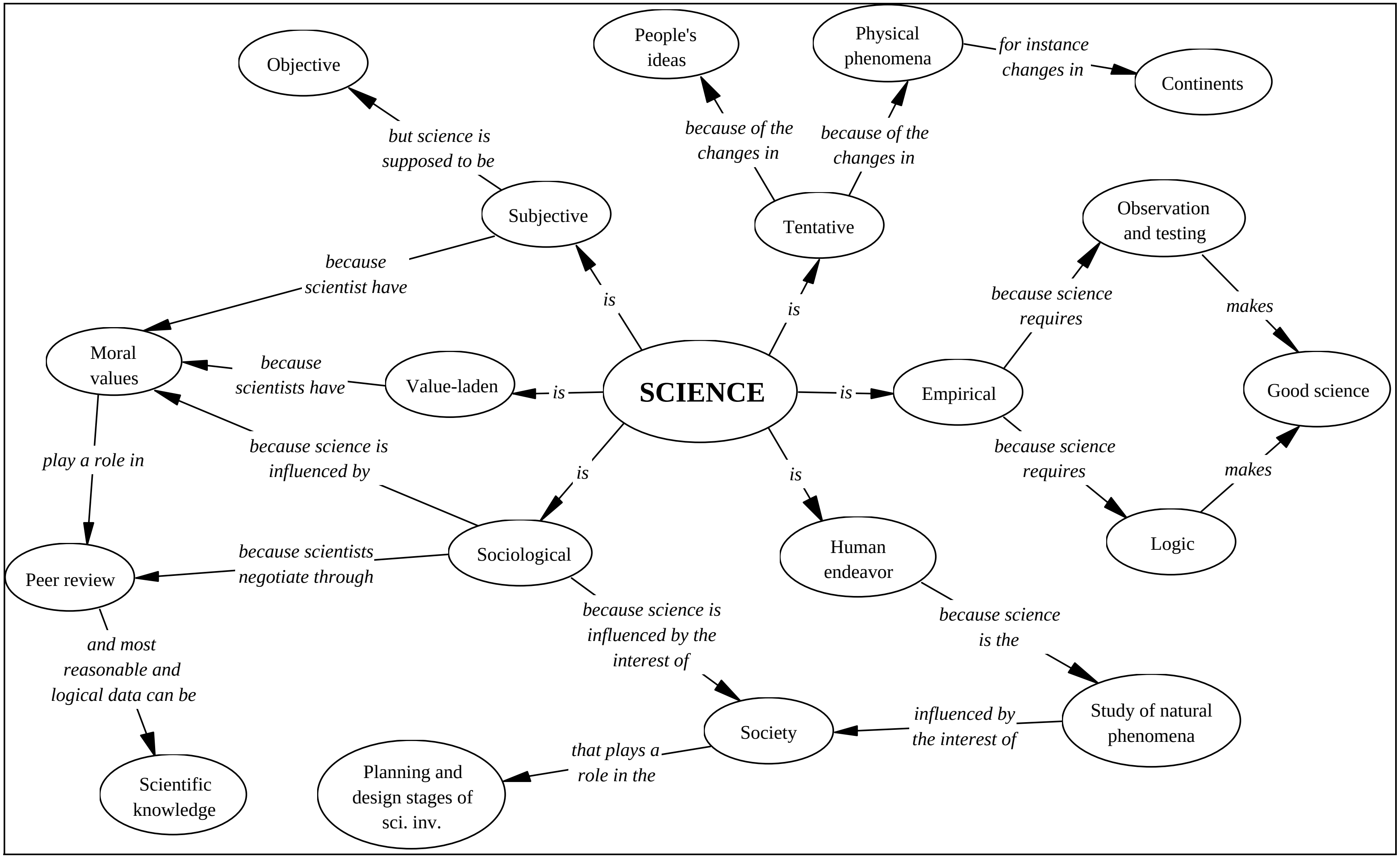

Figure **5.6**: Jacob's Post-conceptions of the Nature of Science.

5.2.4.4 Triangulation of the Interview Findings

In this section, I discuss whether my interpretations of Jacob's interview are consistent with his written responses to the philosophy of science questionnaire. In the first part, I compare Jacob's pre-conceptions. In the second part, I compare his post-conceptions.

Part I

In this part, the prepositions I compare are how Jacob (a) defined science in reference to its *empirical* characteristic, (b) distinguished science from other disciplines, (c) pointed out the essence of group work in decreasing the scientific bias, and (d) the influence of human values on the planning and design stages of a scientific investigation.

In both of the pre-instruments, Jacob described science as *empirical*. In the pre-questionnaire, Jacob wrote, "science is a way to study natural phenomena by observation and experimentation." In the pre-interview, he also said science was a way to find out about Nature, through the use of testing and scientific method (Figure 5.5).

In both assessments, Jacob explained how science was different from other disciplines similarly. In the pre-questionnaire, Jacob wrote, "science studies things that are tangible and things that can be tested." In the pre-interview, he spoke the same words: "you cannot make tangible observation *in disciplines other than science* [italics added]" (Figure 5.5).

In the pre-interview, Jacob told me that by working in groups, scientists can ensure that scientific claims are more objective (Figure 5.5). In his written responses to the pre-questionnaire, he implied similarly. He wrote:

> Outside input when it comes to science may be more helpful in that it is more objective in interpretation as opposed to someone's opinion on a piece of art or a piece of literature.

In both assessments, Jacob articulated that others' opinions helped science to be more objective (and so less subjective).

In the pre-interview and the pre-questionnaire, Jacob reported similarly, "science couldn't achieve complete objectivity." In the pre-questionnaire, he described the influence of human values in science as "every person is influenced by his or her past experiences and goals that, what this person focuses on researching will also be influenced." In both pre-assessments, Jacob referred to the planning and the design stages of a scientific investigation as being influenced by human values (Figure 5.5).

Part II

In this part, I compare the propositions of how Jacob (a) defined science in reference to its *empirical* characteristics, (b) distinguished science from other disciplines, and (c) described the role of group work in legitimating scientific claims.

Jacob's definition of science was consistent both in the post philosophy of science questionnaire and in the post-interview. In the questionnaire, Jacob defined science as follows.

> Science is a way of findings out how natural phenomena works, worked in the past and may work in the future. Science is a way of thinking analytically and critically in order to solve problems.

Jacob distinguished science from other disciplines in terms of how scientific claims are tested and what these claims are based on. His responses emphasized the *empirical* characteristic of science in both instruments (Figure 5.6).

Neither in the interview nor in the questionnaire, did Jacob affirm that scientists work in groups in order to increase the objectivity of scientific claims. In his post-questionnaire responses, Jacob mentioned that group work was important in science classrooms because this was exactly what happens in real science. He made a similar comment in the post-interview (Figure 5.6). In the post-questionnaire, Jacob wrote:

> Group work is important in all fields of study, but it is especially important in the science classroom because that is how real science is conducted.

In the post-questionnaire, Jacob commented that effective science teaching should have included the methods similar to those scientists often engaged in. He wrote:

> Effective science teaching practices the methods used by the real scientists. Being able to constructively criticize someone else's work and one's own work is a sign of understanding the material compared to just memorizing the facts. In the science industry where products are invented and research is conducted, group work is seen very common.

Since we did not talk about effective science teaching strategies in the post-interview, I cannot compare whether the above statements are consistent with the interview findings. I do not find this missing link problematic, because this study does not focus on participants' perspectives of effective science teaching strategies, even though I believe it is important to consider. Here, I present the above excerpt because Jacob's thoughts about effective science teaching will help the reader to better comprehend the discussion in the next chapter.

The consistency of the propositions I compared in this section show that my interpretations of Jacob's interview transcripts and his written responses are similar.

5.2.4.5 Changes in Jacob's Conception of the NOS.

After the CPR project, I observed dramatic changes in Jacob's portrayal of science, specifically about the *sociological* NOS. Jacob did not report differently about his conceptions of the *empirical, subjective, value-laden,* and *human endeavor* characteristics of science, before and after the project. However, in explaining why science was *subjective, value-laden*, and a *human endeavor,* he often provided evidence regarding the *sociological* NOS, and he did so after the CPR project. Since I was unable to depict Jacob's pre-conceptions of the *tentative* NOS, I assume they did not change, and if they did, this study did not capture the differences.

Jacob explained the objectivity of science quite differently in the pre and the post-interviews. In the pre-interview, he argued that scientists work in groups in order to eliminate, or at least decrease, any personal bias. This would eventually increase the objectiveness of their scientific claims, regardless of the fact that science could not achieve complete objectivity. In the post-interview, Jacob did not claim that scientists working in groups were more likely to state more objective scientific claims than were scientists working individually. He rather pointed out that group work was essential in legitimating the scientific claims that were often achieved through peer review. Jacob did not change his conceptions about the *subjective* (or the objective) NOS, but he revised his understanding of the reason scientists work in groups.

In the interviews, Jacob reported differently about the scientific facts. In the pre-interview and during the first half of the post-interview, Jacob argued that scientific facts were physical reality independent of human mind. In the pre-interview, he supported this argument maintaining that scientific knowledge was changing, because Nature was changing (e.g., continents and the associated scientific knowledge). Not until the end of the post-interview, did Jacob assert that scientific facts were actually human thoughts and explanations of Nature but not the Nature itself.

In his pre-responses to the philosophy of science questionnaire, Jacob reported that the objectivity of science could be achieved through group work and others' input. In his post-responses, he commented that through peer review, students learn how to critically analyze each other's work. He further explained that peer review actually happens in real science and so it was a means of students acquiring an understanding of actual scientific practice.

Jacob dramatically changed his views on how scientific claims were accepted by the scientific community. In his pre-interview responses, he referred to "testing again and again" as the means by which scientists negotiate and legitimate scientific knowledge. In the post-interview, he explicitly mentioned "peer reviewing" in scientific communities and its role in negotiating the validity of scientific claims. He emphasized that the best "logical" explanations were more likely to be accepted by other scientists. He further commented that there was a scientific authority that most likely decides if a scientific claim is to be negotiated or rejected.

5.2.4.6 Jacob's Experiences with the CPR Project

The analysis of Jacob's interview transcript revealed that Jacob especially liked the original research and the peer review aspects of the project. Jacob suggested deleting the numeric scoring scale from the peer review so that reviewers would provide more qualitative feedback. Jacob found the peer review aspect unique, because it provided opportunities for students to revise their final reports. Jacob agreed with his peers' evaluations of his report and made the chances they suggested. However, he did not think the suggested changes significantly improved the quality of his final published report. Jacob told me that he would use a similar peer review system when he starts teaching, but he was unwilling to allow students to grade each others' work.

In the following paragraphs, I describe Jacob's experiences with the CPR project along with the excerpts from the post-interview. The instrument (Semi-structured CPR Interview Protocol) I used to explore Jacob's experiences is presented in Appendix C. I also illustrate some of Jacob's responses to the final student questionnaire (Appendix F) regarding his experiences with the CPR project.

Jacob especially liked the peer review and the original research aspects of the project. He said that reviewing other people's lab reports helped him to learn how to provide constructive criticism. He said:

> I liked reviewing other people's lab reports, because that's something that I will have to do as a science teacher. So that was very useful or helpful in practicing constructive criticism.

Jacob found it exciting that the experiment he conducted was not performed before.

> It was a simple experiment that could be useful. I don't know if our findings are going to be or if ever going to be used because in the beginning Dr.Carlsen was saying that a lot of these toxicology tests have not ever been done. There are so many combinations of solutions and not all have been solved, so to think that maybe, you were the first group to conduct this experiment, I think that's cool. I think it's a nice feeling, to know that you are the first group that investigates that. That's science, that's cool.

When I asked Jacob to talk about the parts of the CPR project that he least liked, he said:

> There was nothing that really disliked. I didn't feel uncomfortable at all. I was peer reviewed but my reviews were not anything personal or too critical or anything like that.

I asked Jacob once again if there were some parts that he would like to change or would like to see performed differently and he responded:

> They [others' review of Jacob's original report] weren't bad, nothing major. Nothing insulting; nothing saying that I should know more about this or that. The one thing that I didn't like about it actually, now I think of it, I like the whole idea of the peer review, but there was also a numerical system. You could give a person three out of five or something and then explain your suggestion. Some people would give me three out of five and write, for example, you misspelled this or something. I mean, that's not an error and they didn't give me full credit, which is okay. I didn't deserve the full credit, but they wouldn't explain the rational to me well. So I think if I were in charge of it I wouldn't assign these numerical values to the peer review. I definitely like the idea of the peer review, for example the suggestions in order to make it better but that affected my grade. You know, by whatever big amount or small amount, it still had an affect, you know what I mean? I mean, I don't really care about the grades so much, but the professor knows the scores that you gave for your reviews and I think that people might think that they shouldn't give full credit even if they don't think anything might be wrong. They just get the feeling like, you know, this isn't the best report, so like I have to take some points off here or there so I don't look like I am just giving full credit and not putting any effort into it. So yeah, I didn't like that part, but overall, you know, it was a pretty good exercise.

In the above excerpt, Jacob pointed out his concern for being quantitatively scored without being provided with a rationale. He suggested taking the numeric scoring system out of the peer review so that reviewers would focus on providing qualitative explanations of their feedback that would be more constructive than numeric scores.

Jacob also indicated in the final student questionnaire that he was in favor of knowing the identity of authors. He responded that he disagreed (scored 2 out of 5) with the item: "It is easier to say what I really think when I don't have to sign my name or meet in person with the students who wrote the research reports."

Jacob reported that the peer review aspect of the project was unique. According to Jacob, peer review provided students opportunities to see their mistakes and learn from them. Thus, their final reports would have fewer mistakes which would result in higher course grades.

> In this toxicology experiment, you had a chance to revise your report, whereas in a lot of my other classes when you return a report that's it. It gets graded, which is good, because you learn from your mistakes, You can change them and you can learn from that, and then not be penalized with bad grades. Whereas in other labs if you make a mistake, you don't get a full credit. That's it, and you learn from that. You do get penalized with lower grade, and it seems like it's not a big deal, but it is a big deal.

Although Jacob was interested in using a similar peer review with his students, when he begins teaching, he was not in favor of students grading one another's work because students would not be qualified in grading one another.

> Yes I definitely would [use a similar peer review in the future]. I wouldn't allow the students to grade each other. I wouldn't allow their peer reviews to influence other students' grades. But the idea of reviewing each other's work is excellent.

In another instance, Jacob responded similarly:

> Actually, I guess I could say no [to allow students grade each others' work] because Dr. Carlsen is definitely more qualified to give grades, than, say, one of my peers who never graded a lab report in his or her life. No, I don't feel comfortable with the fact that these student who may never have graded a lab report affect my grade. This may be sound like I care about grades too much but really I don't.

In the final student questionnaire, Jacob reported that he strongly agreed (scored 5 out of 5) that meaningful peer review was a reasonable expectation for college students. He was positive that meaningful peer review would have been a reasonable expectation for high school students, with less scoring; 4 out of 5 (agreed) (Appendix F).

When I asked Jacob, if there are any other parts he would like to redesign when he uses a similar peer review with his students in the future, he said there was nothing he would change; it was an excellent exercise.

> I liked, like I said before, I liked the experiment. It was simple and it had implications that you might have been doing something that no one else has ever done. It was real science. It was an excellent experiment.

Jacob agreed with his peers' evaluation of his work. He found the recommendations helpful in improving his final published report.

> Yes, I thought the errors they pointed out were valid, and I thought the score they gave me was fair.

Jacob also told me that he learned something new from others' evaluation of his work. In the peer review process, Jacob learned about the importance of reviewing his work after it was completed.

> Yes, I learned to look over all of my work all. It's very important. I do this in my work where I don't have confidence. When I have confidence in my work at times and I will go through it and I would not look over it again, because I might have done it before.

Jacob changed some grammatical and spelling mistakes in his original report based on the reviewers' comments. He responded that the improvement was small but significant.

> I corrected some spelling errors. I might explain one question more thoroughly, but I have done a lot of labs. I am satisfied with my own work but spelling errors or something like that I am not good at pointing out. So did it improve? Yes. Did it improve a lot? No.

In the final student questionnaire, Jacob reported that he received useful peer review comments about his own report (scored 4 out of 5) (Appendix F). Jacob reported that he disagreed that he changed his mind about something in his report because of comments he received through peer review (scored 2 out of 5). This is probably because the reviews he received focused more on grammatical and spelling mistakes.

Jacob thought it would be difficult, but not impossible, for him to make the changes his reviewers' suggested, if his on-line published report had not been reviewed by someone else, but he was asked to revise it later in the semester. Jacob was also reported neutral to in the final student questionnaire (Appendix F). He scored 3 out of 5, to the item "I changed my mind about something in my report because of comments I received through peer review."

> Maybe I could [make the changes]. Pointing out your own errors is more difficult than someone else is pointing out your own error. Like reading your paper, you read your own paper eight times and it all sounds right, because you wrote it, but someone else will read it and it doesn't sound right. So maybe not. Maybe I would, maybe I wouldn't.

Jacob did not make other suggestions to improve the CPR project in general. Even though, I asked him to comment on the format, structure, and organization of the whole project, he did not advise any changes. He said:

> Umm.. no it's, that's fine. I remember for the most part, I thought it was a good project. I thought the questions were important. Would I ass anything new? No. I thought the questions were really good. They went it over what would you change about this experiment? Why do you support the conclusions you have came to? What evidence did you come up with? I mean, those kinds of questions, those are found in all sorts of labs, so I thought it was good.

5.2.5 Case 4: Liz

5.2.5.1 Liz's Demographic Information

Liz, a pseudonym, was an undergraduate student majoring in the field of Science Education with an option in Chemistry at the time this study was performed. Her secondary major field of study was general science. Liz was expecting to graduate in 2003, the same academic year this study was conducted. She did not have any research experience in a setting other than a conventional college class prior to this investigation.

5.2.5.2 Liz's Conceptions of the NOS before the Activities of the CPR Project (Pre-interview Findings)

Before the activities of the CPR project were started, Liz reported that science was *empirical*, *tentative*, *subjective*, and *value-laden*. She did not mention the *sociological* characteristics of science in her portrayal of science. Liz's pre-conceptions of the NOS are summarized in Figure 5.7 and described below.

Liz defined science as "a way to make sense out of just the random things that you can find in the world." She referred to the physical reality as the study context of science. According to Liz, the roles of scientists were to (a) find patterns in the physical world, (b) relate these patterns with each other, and then (c) put them into categories. A major characteristic of these patterns was their visibility to human sensory organs, particularly vision.

Liz distinguished science from other fields of inquiries with respect to its *empirical* characteristics. Observation and experimenting were considered two distinctive characteristics of scientific claims (Figure 5.7). Liz did not believe that paradigms other than science might use different proof systems and logic to legitimate their claims. She perceived proof in science as the most, if not the only, valid way of explaining the phenomena humans have encountered. She further articulated that in science you can prove your arguments, whereas in other disciplines (religion or astrology) you cannot. Liz said:

> I just read it [horoscope] for fun, and see if anything they say actually happened in the future or not. This makes me think that it is not science. Science is something that I trust, but I don't trust in astrology, because in my experience it isn't reliable. You know, it says something is going to happen, and we know that it obviously will. I guess, trying to relate to science, it just seems that there is no truth there [in astrology], like in science. In science you have actual things that you have observed and that you can repeat. You can actually take these things that you observed and put them into a different setting and you know, make everything the same. You can do it again and get the same results. I don't know how they make up horoscopes, but it just doesn't seem like you can take astrology out of the context that it's in, put it in some other context and get the same results. I don't really know much about it, you know, to say with authority, but that's my understanding of it.

In the above excerpt, Liz stresses that she trusts claims in science more than other claims in other disciplines because scientific claims are reliable and repeatable.

When Liz talked about objectivity in science, she said, “science starts to be objective but it cannot completely be objective.” She explained that achieving complete objectivity in science was difficult because scientists are human and it is almost impossible for humans to think completely objective.

Regarding the *value-laden* characteristics of science, Liz responded that human values influence science (Figure 5.7). She explicated that science is value-laden because cultural backgrounds and personal worldviews affect how scientists think before they start their investigations. She stated:

> I think it’s pretty impossible not to have your personal views that your culture affects what you are doing. You know, if you have two scientists working on the same problem, and they are from two completely different cultures, and they believe completely differently, the way they think is affected by their culture. The way they think is going to affect how they do their work . So their culture does have more of an affect. They are obviously not saying okay, I believe A is true, and I am going to prove it no matter how much evidence I see that A might not be true. They wouldn’t do that, but they would still be influenced by things they learned over the years, and the rules that their culture is set up. So that, you know, they might value something more than others. So they would consider looking at that thing before something else, you know, consider looking at that as a cause, or using a particular method, even though they could consider some others.

In the above statements, Liz expressed concerns about scientists’ cultural and personal worldviews as the influencing parameters of how scientists think and look into things. She stressed that the planning and the design stages of scientific practice were subject to scientists’ cultural and personal worldviews (Figure 5.7). Liz did not state that scientists’ cultural and personal worldviews might play a role in the interpretation stage of scientific knowledge.

Liz defined a major characteristic of a scientific fact as “something that is repeatable in many different circumstances.” She stated:

> I guess, scientific fact would just be something that is repeatable, and reliable I guess, you know, you can count on it happening every time.

Liz said, “scientific facts are that you actually see.” Liz distinguished scientific facts from other facts in accordance with human sensory organs, particularly vision.

> I think a lot of science is something visual, something you actually see. The pen falls, whereas philosophy and religion are ideas that don’t have visual affects. So you can’t see the one god or many gods. That is the difference.

Liz thought scientific facts were not stable and fixed, noting that scientific facts were 75% stable. On the other hand, in some of her other responses, she specified that scientific facts were actually the physical reality. Liz strongly held the assumption that there is an explicit, outside reality independent of human thought and experience. The following statement illustrates her conceptualization of reality.

> The scientific facts are going to be there whether people are there or not.

According to Liz, before scientists accept a scientific claim, the claim must be subjected to many tests that all verify the same conclusion. This same effect can be achieved through peer review. She stated:

> They [other scientists] probably have to do the experiment and see if it comes out the same for them, and then also think about whether or not it violates any commonly accepted things. If an experiment violates a commonly accepted principle, which mean that probably something was done wrong, a scientist also looks at what was done, and then tries to inverse it. So if you are saying that A goes to B, you see if B will go back to A.

In the pre-interview, Liz did not refer to the peer review and did not express the role of scientific community in generating scientific knowledge in any of her responses other than the above statement.

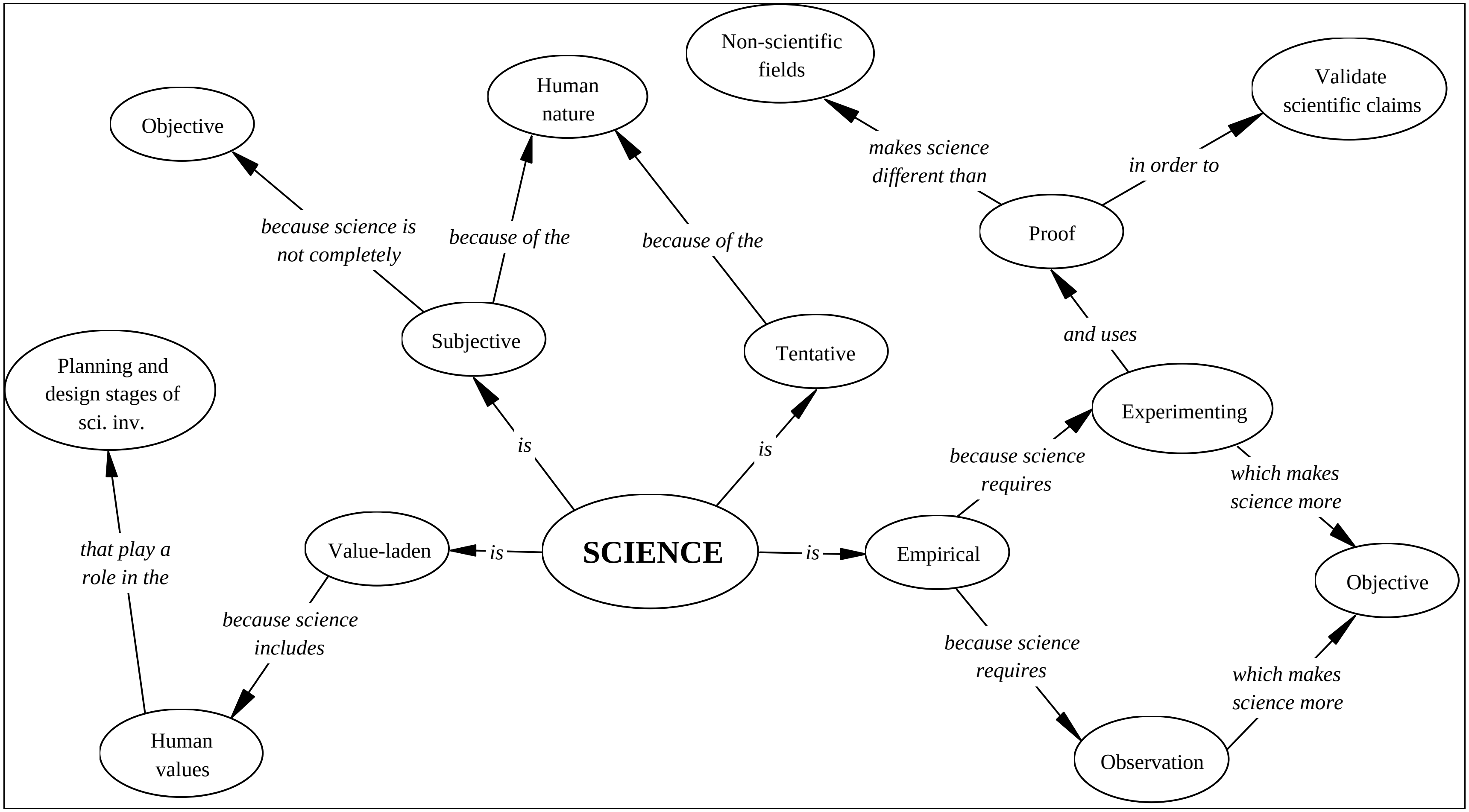

Figure **5.7**: Liz's Pre-conceptions of the Nature of Science.

5.2.5.3 Liz's Conceptions of the NOS after the Activities of the CPR Project (Post-interview Findings)

After the activities of the CPR project were completed, in the post-interview, Liz described science as *empirical, tentative, subjective, value-laden, sociological,* and a *human endeavor*. Liz explained these characteristics of science in reference to "peer review" and portrayed an understanding of the *sociological* NOS. In Figure 5.8, Liz's post-conceptions of the NOS are represented. Below, her post-conceptions are described.

In the beginning of the post-interview, Liz defined science as:

> Science is finding patterns in Nature, which seems to be this big random and science is finding the link between things, discover how they work, and make predictions.

For Liz, what distinguishes scientific paradigm from other paradigms are the reasoning and the logic science utilizes. She further stressed that scientific facts were different from other facts because "you can actually see and touch" the scientific facts.

In the post-interview, Liz pronounced scientific facts as true claims that were not proved otherwise. She said:

> I think scientific facts are things that people have spent time on and then worked with, studied, and found that they can't find any circumstances in which it doesn't hold true. That's pretty much what I think a scientific fact is.

Liz's answers regarding the definition of facts were vague. She described scientific facts as the explanation of facts that were inherent in Nature, noting:

> I believe there are inherent facts in Nature; we just haven't found the best way to express them yet. We are still working towards that and that's why it [scientific facts and claims] changes, but I think the facts themselves don't.

The above statements reveal that Liz held the assumption that there is an explicit, outside reality independent of human thought and experience. On the other hand, she did not agree that scientific facts were fixed and stable. Rather, she viewed scientific claims are *tentative* and subject to change. The reason science is *tentative* is because scientists review each other (Figure 5.8). She stated that:

> Because there is no way to tell absolutely [referring scientific facts], like in history, if you are trying to decide how the earth formed, or whatever, there is no way to go back and see. You can't know that for sure. So someone else later on will find something that makes more sense, then people are going to believe on them instead of you. So there is always a review process going on.

Liz commented that human values, such as cultural backgrounds and personal worldviews, are prominent in the planning and the design stages of scientific practice (Figure 5.8). She said:

> I think there is a lot of value in science, because it solves problem, so people value science itself and scientists go into science with this valued mind set that what they are doing is valuable. So you know, this makes all their ideas more valuable than they might otherwise be. Then the things they believe to be right or wrong, they grew up with, and they were taught by society are also then brought into their work. So, for example, the whole cloning issue that's coming up now, our society has taught everyone you can't create life. This raises a lot of issues with cloning and makes a lot of people think that cloning is bad and it shouldn't be done. So it influences science. This is one of the ways that society influences science.

From the above and other comments, one might conclude that Liz believed a scientist might or might not choose to study cloning based upon her cultural background or personal worldviews. Liz did not see human values as important in the data interpretation stage of science (i.e., on idea generation or scrutinizing inconsistent results).

Surprisingly, Liz asserted that human values might a play role when scientists publish a scientific report (the stage when scientific claims start being legitimized) (Figure 5.8). She stated:

> If there was a scientist who was making something that could help the cloning industry, or whatever you want to call it, they might think twice about publishing their work, or you know, releasing it to the public. Depending upon whether they disagree with cloning or agree with it, then they might be more likely to put it out there and let people use it.

Liz noted that her conceptions about science and scientists had evolved:

> When I was in high school, I remember learning about science, and thinking, well they [scientists] must be kept really lonely, you know, just doing your work, and not seeing anyone. I don't know if I am learning about more recent studies, or if I am just seeing things more clearly now, but it seems like there are a lot of collaborations and working together between scientists.

In the above statement, Liz noted that her conceptualization of science as a social activity had evolved toward a more social constructivist view of science.

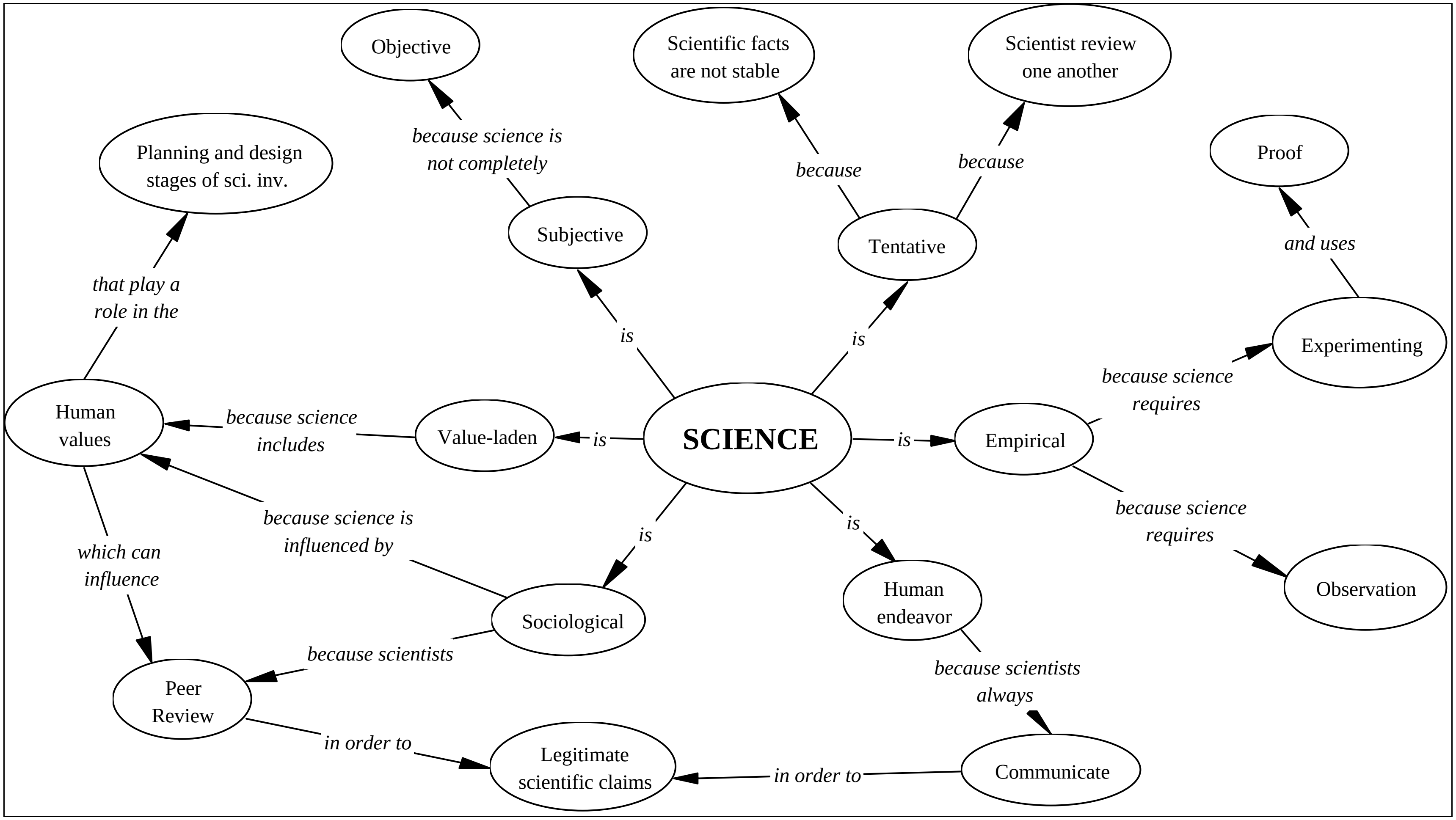

Figure **5.8**: Liz's Post-conceptions of the Nature of Science.

5.2.5.4 Triangulation of the Interview Findings

Analyses of Liz's comments in both the transcribed interviews and written responses to the philosophy of science questionnaire revealed similar propositions. In this section, propositions related to Liz's understanding of the NOS are illustrated by providing evidence from the both instruments. In the first part, I present evidence from the pre-interview and pre-administration of the questionnaire. In the second part, evidence from the post instrumentations is represented.

Part I

The propositions I compare in this part are about how Liz (a) defined science as a way to make sense of the physical phenomena, (b) distinguished science in reference to its *empirical* and objective characteristics, and (c) described the *subjective* NOS.

In both the pre-interview and pre-questionnaire, Liz defined science as a way to make sense of the physical world and to find patterns that exist in Nature. In the pre-questionnaire, she wrote, "Science is making sense of the world. It [science] is finding patterns that help people to understand things" whereas in the pre-interview, she said, "science is a way to make sense out of just the random things that you can find in the world."

In the pre-interview, Liz explicated the *empirical* characteristics of science (Figure 5.7). She mentioned observation and experimenting as the unique characteristics of science that make science more truthful and reliable. Similarly, in her responses to the pre-questionnaire items, Liz emphasized that science differed from other fields of inquiry because it was more fact-based whereas the others were subjective. She wrote that:

> All of the others [disciplines rather than science] are subjective, while science is more fact-based. There are some conclusions in science that must be inferred or are based on opinion, but they are generally based on undisputed facts.

In the pre-questionnaire, Liz reported that scientists worked in groups particularly because there were so many things going on in science that one could not handle all of them individually. She emphasized the importance of students working in groups in science classes in order that they might gather the correct data. Liz firmly believed that by working in groups, scientists (or students) could better formulate excessive or missing data. She wrote:

> I think both sciences and social sciences/arts need group work. The social sciences and arts get many viewpoints, which makes the groups understanding richer, and science has a broader fact- and experience-pool to relate the new material to things the students have already mastered. Science also sometimes has more going on than one person can monitor, so groups are helpful here also. Generally, science classrooms have lab partners- two students who work together to complete an assignment/experiment. I think this format is fine, but slightly larger discussion groups once the experiment is completed might help students understand, especially if their data is incomplete or incorrect; it is difficult to draw the right conclusion if you don't have the correct information.

In both pre-instruments, Liz mentioned that complete objectivity was impossible to obtain. The rationale she provided was the same in both the pre-interview and the pre-questionnaire: scientists choose to study particular subjects because of their cultural and personal values. In the post-questionnaire, Liz wrote:

> There is always some form of the investigator's interests in the experiment, for the mere fact that they did the experiment. The investigator's background also influences the way that they think, so it colors their conclusions. Objectivity is a good thing to strive for, but it is not totally feasible.

Liz did not mention the *sociological* characteristics of science in her pre-interview and pre-questionnaire responses.

Part II

In this part, I discuss how Liz (a) defined science as a way to make sense of the physical phenomena, (b) distinguished science in regards to its empirical and “visible to human eye” characteristics, (c) described the *subjective* NOS, (d) illustrated the *value-laden* NOS, and (e) expressed an understanding of the *sociological* NOS.

In the post-questionnaire, Liz stated “science is making sense of the world; finding order in what seems like disorder; making predictions about what will happen in new situations.” This definition of science is consistent with how she defined it in the post-interview.

In the post-interview and in the post-questionnaire, Liz distinguished science from other disciplines addressing the physical existence of Nature and the *empirical* characteristics of science. She believed that “you actually see and touch” the scientific facts. In the questionnaire, she wrote:

> Science proves its facts by making observations and drawing conclusions. It focuses on physical things, things that you can see and touch, but also things that have visible effects but themselves must be inferred. Liberal arts also prove facts, but they use different methods to do it. Rhetoric is much more influential for disciplines such as religion and philosophy.

Liz added, “liberal arts also prove facts.” However, my analysis of the post-interview transcript revealed that Liz actually believed there was only one, or one best, way to proof a claim (through logic and scientific method). In that sense, findings in regards to how Liz perceived “proof” from the post-interview and the post administration of the philosophy of science questionnaire are not consistent with each other. However, I do not find this inconsistency problematic, because the focus of this study is to explore participants' understanding of the *sociological* NOS that is not directly related to how participants perceive "proof" in science and in other disciplines. Participants' views on the reliability and validity of "proof" in scientific and non-scientific paradigms are not of primary research interest.

In the post-questionnaire, Liz mentioned that group work in science education was essential because it did not only help students to gather data from multiple perspectives but also prompted an understanding of a *sociological* NOS. She pointed out that working in groups can help students better picture the actual scientific community. She wrote:

> Group work in science serves many purposes. For one thing, it allows multiple things to be observed at once. Science in part is finding patterns by observing phenomena; often in labs, there is too much happening for one student to watch it all and write down observations. Another benefit of science group work is that students all bring different background information and fields of expertise. The combination of these varying skills leads to a richer experience for all the students. Finally, professionals in the science community routinely collaborate with each other. Allowing students to work together gives them a better picture of what the science community is like. The main drawback to group work is something that is found in all subjects-- some of the students might end up doing the majority of the work. However, I feel the benefits of working together outweigh the harm it might cause.

In both post instruments, Liz indicated that science attempts to be objective but cannot achieve it completely because of human nature. In the questionnaire, she wrote:

> Objectivity is an admirable trait which the science community attempt to instill in its members. Achieving objectivity is not as simple. Everyone's thought processes are influenced by the society in which they live, and this affects the conclusions they draw, the questions they ask, and the information they accept as valid. The simple fact that a person is studying a topic denotes personal interest, which makes objectivity slightly harder.

In the above statements, Liz expressed concerns regarding the *value-laden* characteristics of science; cultural and societal backgrounds of scientists influence the planning, design, and legitimating stages of scientific knowledge, but not necessarily the data interpretation stage.

5.2.5.5 Changes in Liz's Conceptions of the NOS

Liz did not dramatically change her understanding of the *empirical, subjective, tentative,* and *value-laden* characteristics of science. Dramatic differences were apparent in her explanations of the *sociological* NOS. In the post-interview, Liz explained how scientific collaborate in regards to *tentative, subjective*, and *human-endeavor* characteristics of science, and how this collaboration resulted in generating scientific knowledge.

I observed that Liz's explanation of scientific facts in the pre-interview differed from her explanations of scientific facts in the post-interview. In contrast to the pre-interview, in the post-interview Liz was less confident with the assumptions that there was an explicit, fixed reality independent of human thought and engagement, and that scientific facts were inherent in this reality. I cannot say that Liz changed her conceptions of the scientific facts. However, I noted that in the post-interview, she did not mention a direct relationship between physical reality and scientific facts just as she did in the pre-interview.

In the post-interview with Liz, she often addressed the peer review aspects of science in her explanations regarding the *tentative* characteristics of scientific claims. She maintained that scientific claims were changing because there was always a review process going on in scientific community. That kind of understanding of science is significant because it reflects a view that science (normal or evolutionary) is progressive as well as a dynamic entity and therefore subject to change as to new findings emerge.

In the post-interview, Liz emphasized the role of human values in the legitimating stage of scientific knowledge, a position she did not take in the pre-interview. She said:

> If there was a scientists who was making something that could help cloning industry or whatever you want to call it, they might think twice about publishing their work, or you know, releasing it to the public. Depending upon if they disagree with cloning or agree with it, then they might be more likely to put it out there and let people to use it.

In the pre-interview, Liz was referring to the way people think when she described the *value-laden* characteristics of science. After the CPR project was completed, her explanations regarding the *value-laden* characteristics of science seemed to have evolved. She held that scientists were free to choose one of many answers and decide whether to publish them.

5.2.5.6 Liz's Experiences with the CPR Project

After the activities of the CPR project were completed, Liz reported that she liked the original research aspect of the project and she found the peer review aspect unique. She agreed with her peers' reviews of her original report, made the changes they suggested and found those changes helpful in improving her final published report. Liz would consider using a similar peer review system when she begins teaching. She reported concerns about the delay in getting her reviews from the other participating institutions.

In the next section, I describe Liz's experiences with the CPR project, providing some of her responses in the interview. The instrument (Semi-structured CPR Interview Protocol) I used to explore Liz's experiences is presented in Appendix C. I also utilized Liz's responses to the final student questionnaire, which deals with her experiences with the CPR project (Appendix F).

In the interview, Liz reported that she mostly liked the open-endedness of the experiment that was conducted. Even though the toxicology experiment had its own procedure, students were free to choose a chemical they wanted to test for its toxicity. Liz and her team member decided to use toothpaste.

> I liked deciding what chemical we were going to use as a toxin, thinking about all the things, you know all the different choices we had. We ended up using toothpaste, the sodium fluoride and the bicarbonate. We were trying to see if that would be a toxin in high concentration. I thought that was really interesting, you know, just looking through all these chemicals and trying to see what might be toxic.

Liz reported that she did not receive reviews for her original report on time. She said:

> Actually, when you have the peer reviews done - we all posted ours around the same time and then people would do peer reviews periodically. But I think the other colleges were posting theirs, and then not doing the reviews quite as quickly, so we were all supposed to revise ours and then publish them. I haven't had any reviews done because I guess some people in our class have been doing other schools, and some of the other schools haven't done their reviews, or something. I don't know what had happened. I didn't have any reviews done, so I couldn't revise my report and publish it, because you have to have reviews before you can have it published. So we had people in our class do extra reviews. So that was the only big problem, kind of a logistics thing, just trying to get everything done on the same schedule. With all the students who did it being in different universities, it's probably really hard to get everyone together. That was the only thing that I remember really sticking out.

Liz made changes to her original report based on the reviews she received. She said that the reviews of her report were helpful and constructive.

> I think they did [reviews helped]. It's nice to have a perspective that is not your own, because if you try to review something that you did yourself, things obviously seem clear to you, because you know everything behind it. But they might not be clear to someone else. So it's good to have fresh eyes look at it and see where you might have missed something, and just forgot, because it was a like second nature or something you are expecting to be there.

Liz found the peer review aspect of the project unique. When I asked her to compare her experiences in the CPR project with her other in-class or laboratory experiences she said:

> I really liked it [the CPR project] because of the peer review. It gave you time to write what you thought and then have other people, who done the same thing, give you input and say little bit about it. I thought that was nice, because it gave you time to think about it before I publish it. I found that after I write something and then turn it in, oh, I should have changed it. This gives me time to do that. I liked that.

Liz reported that she would have not made the same revisions she made, if her on-line published report had not been reviewed by someone else, but she was asked to revise it later in the semester. She responded neutral (scored 3 out of 5) to the item "I changed my mind about something in my report because of comments I received through peer review" in the final student questionnaire (Appendix F).

Liz told me that if they had the chance to conduct the same experiment a second time, they would definitely consider using the concentration reviews suggested.

> There was one [reviewer's comment] that brought up a point that I hadn't thought of: something about what we were asked when we were writing our rough copy or suggested to improve if we were going to do the project again. I had said, you know, starting at ten [percent concentrations] and moving down, I'll try to see exactly where it becomes toxic. One of the comments said, "Maybe you should start a little higher, like 50 percent [concentrations]."

Liz agreed with her peers' evaluations of her work. She stated:

> Yes, I got kind of middle evaluation numbers and that seemed reasonable, because I did really think about it, but I didn't think deeply about every question. I just had an answer.

In the final student questionnaire, Liz agreed (scored 4 out of 5) with the item: "the quantitative scores I received from peer reviews were fair" (Appendix F).

In the interview, Liz responded positive that she would think about using a similar peer review system with her students when she begins teaching. In the final student questionnaire, Liz also agreed with the item: "If I taught science, I would like to use some type of formal student peer review" (Appendix F).

Liz thought it might be too difficult for K-12 students to complete a similar project, given their capabilities. She was concerned that students would not be able to critically reviews of one another's report

> I will think about it: I will definitely think about it. I think it might be a lot of work for them to do on a regular basis because you have to do yours, and then you have to think about somebody else's. It's a lot of critical thinking, and I don't know, depending on what grade level I will end up with, they may not be ready for that. I think the process of reviewing someone's work is a lot of work and I don't know if high school students would be at that mental level, or if they will be ready to do that critically. They may feel kind of weird, like, "Oh they are my classmate. I can't be mean to them." But sometimes you have to be mean about it - not mean about it, but you have to say to them something that might be taken as mean. So maybe once in a while, like twice a year, but not more than that.

In the final student questionnaire, Liz agreed (scored 4 out of 5) that meaningful peer review was a reasonable expectation for college students as well as for high school students.

Liz thought that engaging in a peer review system would help students better understand science and its enterprise.

> I think it's a good thing for them to have at least once so they see what happens in science.

Liz suggested running the experimental procedure one more time, after the students review each others' work and the work is published. She particularly recommended that, K-12 students run their experiments a second time, after they receive reviews from their peers. Liz said:

> It would be kind of nice if we could have done the experiment once again after we got our results, but before we wrote the report. If we could have gone back and done like a second phase with different levels, I think that would have been nice. Also I think maybe not for the college level, but if we were in the high school level, this sort of project, I think, it's nice that you do have to go to the second level, like the second phase, and tweak what you were doing so that you get better results. So I think, that's a good thing to do.

5.2.6 Case 5: Megan

5.2.6.1 Megan's Demographic Information

Megan, a pseudonym, was majoring in Secondary Education with a Biology option during the present investigation. She was interested in becoming certified in general science so that she could also teach science up to 7th grade. At the time I interviewed Megan, she had not participated in a systematic scientific investigation in a setting other than a conventional college class.

5.2.6.2 Megan's Conceptions of the NOS before the Activities of the CPR Project (Pre-interview Findings)

In the pre-interview, Megan portrayed science as *empirical*, *subjective*, *tentative* and *value-laden.* She pointed out several times that science was supposed to be objective because objectivity is what makes science valuable. Megan's pre-conceptions of the NOS are described below and summarized in Figure 5.9, at the end of this section.

Megan defined science as "everything around us" and an activity of "thinking a lot of, like questioning, exploring, and experiencing things." She explicated the *tentative* characteristics of science as "it [science] is always changing and it is not definite."

Megan told me that the scientific view could be integrated into every aspect of life. She said:

> I think there is a scientific view to everything. Every subject can have a scientific, you know, curve to it if you ever experiment, if you ever do research, if you ever dive into a subject matter more deeply.

Megan thought science is different from other disciplines of inquiry because of the *empirical* characteristics of science (Figure 5.9). According to Megan, scientific claims were observable and supported with evidence; therefore they were easily accepted by the majority of people. Because other disciplines of inquiry (e.g. religion) did not have observable explanations and supporting evidence, it was a personal choice to accept or believe in the arguments they provided.

According to Megan, a scientific fact is something that has been proven with consistent results each time.

> A [scientific] fact is anything, I think, that can be proven. So scientific fact is some aspect of science that has evidence to prove that it happens. And I think that it's something that has to become - it happens every time that you try it. It has to be the same.

Megan reported that scientific facts would still exist even without human beings. She perceived scientific facts as being the physical reality themselves rather than as *human endeavor* (Figure 5.9). She added that there would be no one to know, discuss, and document these facts, if humans did not exist in the world.

> I think yes [scientific facts would still exist, even though human beings did not exist in the world], if people weren't here. Things would still be here. Something would still happen but no one would be here to document it, so there wouldn't be anything to discuss. Like gravity would still happen, I think, and you know, certain things would still occur, but it wouldn't be organized.

To clarify whether Megan viewed scientific facts but not other facts as *human endeavor*, I asked her whether non-scientific facts would exist if human beings did not exist. She responded:

> I think that they [facts in disciplines other than science, e.g. astrology] will exist but a lot of that stuff is for humans. Just like science though, it needs to be organized to make it something that has any kind of meaning. So I think they will exist, but it wouldn't have meaning because no one will understand it. No one will be here to discuss it or to figure it out or to discover it. I guess that's my answer.

Some of Megan's explanations seem to imply that she perceived scientific facts as *human endeavor*. However, I argue the opposite. Megan explicitly stated that gravity would still exist, if humans did not exist. She was referring to a scientific fact by using the word "gravity." After an in-depth analysis, I concluded that Megan had an understanding of scientific facts as either as physical reality, or as the objective reality, but not as *human endeavor*. In fact, when I questioned her, she said that non-scientific facts would exist, if humans did not exist. This supports my interpretation that, Megan perceived neither non-scientific facts nor scientific facts as *human endeavor*.

Megan told me that scientific facts were subject to change and this change was often progressive (Figure 5.9). According to Megan, scientific claims were constantly challenged by people, and through this challenge, more evidence was generated; therefore new claims were more successful (in the sense progressive) than previous ones. Her view that scientific facts were subject to change is consistent with her assertion that science is *tentative* (Figure 5.9). Megan stated:

> People are challenging that [scientific facts], as much as newly created theories or ideas about science, because there is so much evidence. There are so many people who agree with it. So newly created ones are more subject to be progressive because like cancer research, people think they know, but there is so much gray area still there. It's such a progressive field because there is so much yet to learn. So I think most of science is progressive, or general science is progressive.

Megan argued that science was universal because scientific problems were the ones that affect most people. She stated:

> Because science is so universal, it could affect people in United States, people in Europe, you know, it affects a wider scale of people rather than even just a family of people.

Megan told me that to validate scientific claims, one should do “personal research” and others must agree with the proposed claims. One way to achieve agreement is for others to do the same research, in other words, conduct the same experiment. Megan believed that scientists collaborate in order to check the validity of scientific claims and increase the objectivity of these claims. Although Megan believed that “science should be objective,” she also asserted that “scientific claims are subject to change and are tentative.” The reason is “there is so much out there that we still don’t understand a lot of science.” This statement supports my argument that in Megan’s view, science was the true explanation of physical reality.

Megan told me that science was *subjective*--even though it should not be--because people, who have different backgrounds, could not think the same, so their practices varied. This verifies that Megan thought science was *value-laden,* because scientists’ personal worldviews and background influence the design and planning stages of a scientific investigation. On the other hand, Megan stated several times that science was universal; therefore it should be objective.

Megan responded that science was a social activity (Figure 5.9). When I reminded her that in a previous response, she told me that science was objective and that these two characteristics of science need to be reconciled, she said:

> It's kind of tough for me. I kind of have two answers. I know I am answering in two different ways, but I have always thought that science is objective. Science is, you know - it won't work, if it was a variable thing that requires so many dependents or variables to it. I think the reason it works so well, and I think it's universal, is because the scientific world revolves the same way. Everyone thinks the same way, because people in other countries, doing similar research are finding things that we don't know, but their findings help us. So I mean it is all related. We do help each other, and it is a community thing, even though we are from different places. At the same time, however, their question or how they research, or their ethics would be different. What they dive into and what they don't might be different. What parts of science they choose to study, what parts they don't, that will be different, possibly based on the ethics, but definitely it's a social thing.

Even though, in the above excerpt, Megan speaks of science as social, her point really relates to how science is practiced by many people through communication. She did not mention that scientific claims were socially constructed, and so science was a *human endeavor.* My interpretation of the above statements is that Megan believed scientists in different parts of the world are working on the same problem and conducting similar research to find a common knowledge. In that regard, science was considered as a method of discovery which can be practiced by a few or many people, and which does not necessarily require social interaction. This verifies that Megan did not believe science was a *human endeavor.*

Megan did not talk about the *sociological* characteristics of science in her portrayal of science in the pre-interview.

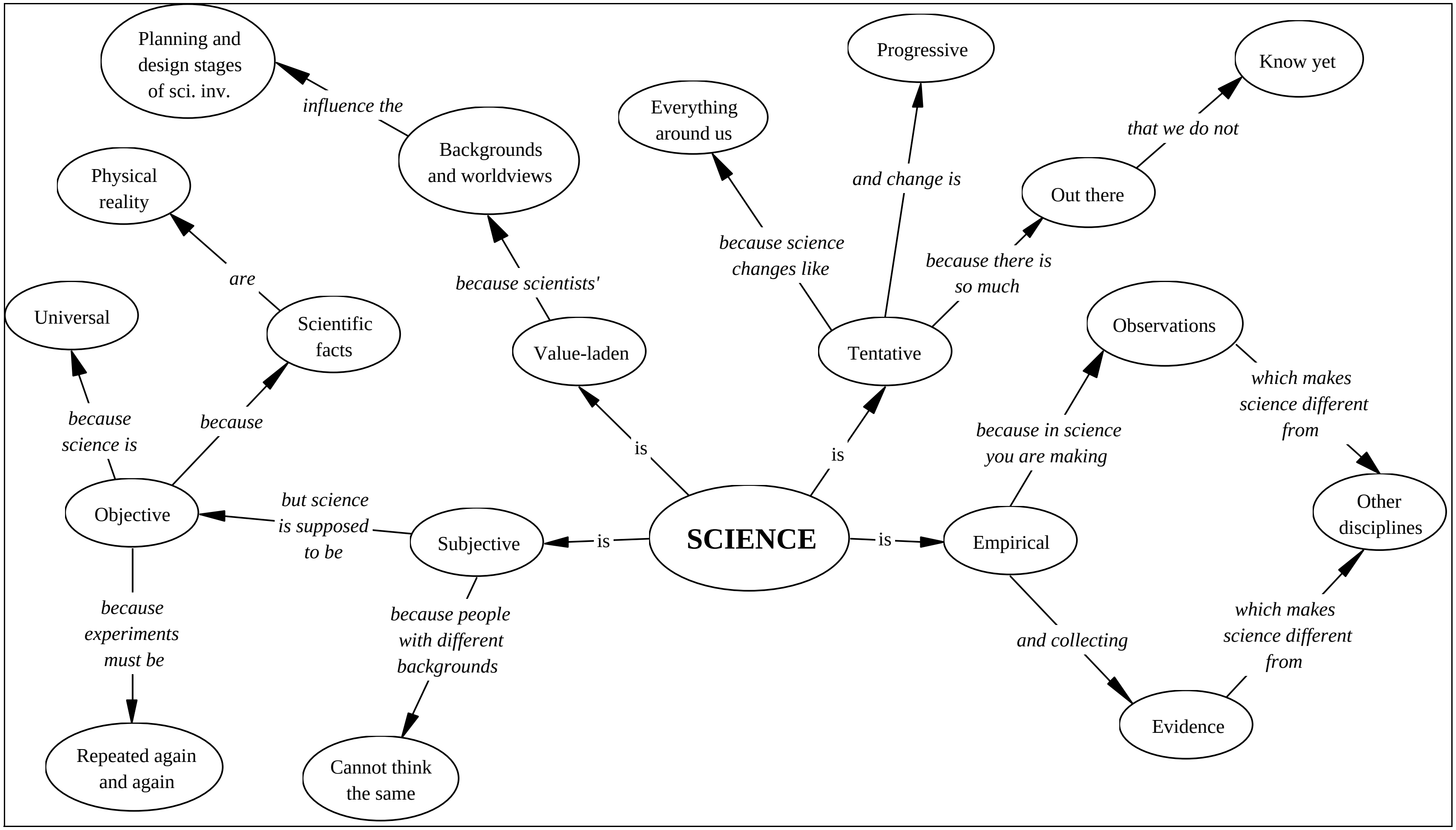

Figure **5.9**: Megan's Pre-conceptions of the Nature of Science.

5.2.6.3 Megan's Conceptions of NOS after the Activities of the CPR Project (Post-interview Findings)

After the activities of the CPR project were completed, Megan defined science as *empirical, subjective*, *tentative, value-laden, human endeavor* and *sociologica*l. Below I describe Megan's post conceptions of the NOS and represent them in Figure 5.10, at the end of this section.

Megan defined science as a process that we follow to explain the world. She pointed out that the *empirical* characteristics of science are involved in observation and data collection to generate evidence for scientific claims (Figure 5.10). Megan also discussed the *tentative* characteristics of science in explaining how the data collected and the evidence generated were subject to change. She stated:

> Science is a process. It involves active participation, finding and gathering data, using experimentation, and concluding results. This is all subject to change all the time because of the different kinds of people doing the experiment, and new information being introduced.

Megan differentiated science from other disciplines by referring to the collaborative characteristics and social aspects of science (Figure 5.10). She pointed out that the way we practice science is different from our practice of other disciplines of inquiry, for instance, how we practice religion. Scientific practice requires more group work and a collaborative environment whereas religion might not. Megan said:

> Science involves working with other kinds of people, and lots of collaboration, and active learning. You can study religion and never have to be in a classroom, or you might have never work with other people, but you can be an expert in religion. But in science, you have to work with people and share ideas, and research. This is a collaborative effort, so it's more working with people.

Megan explained that science required group work, because scientists should share their ideas and come to a mutual agreement, and through this negotiation, scientific knowledge is generated (Figure 5.10). In other types of inquiry, for instance religion, people do not necessarily need to work in groups; they can practice it individually.

> I think a lot of scientists do a lot of research, but in order to really understand all of it, I think, they have to share their ideas and share their data. Science can be perceived in so many different ways, so I think just even if you may not work with someone, like work on a project with someone, but just talk about it and share ideas and stuff, it's the same in religion. When you do share ideas, and you can share ideas in any subject, but science seems to be a time when it's really necessary.

Megan told me that for scientific claims to be validated, others should also accept them. Merely conducting an experiment and finding the same results would not be sufficient for a scientific claim to be accepted as true (Figure 5.10). Megan said:

> I think a scientists personally, they might have run the same experiment a hundred million times and to them its true, but it really doesn't matter, if other people don't believe you. So I think it involves a lot of peer review, a lot of people reproducing the experiment and the results are consistent. I think this is the beginning of making it valid. If I do an experiment and then you do it, and you don't get the same results it wasn't valid. So I think if a community will reproduce it identically or come close to it, and if, your peers and the scientific community will agree with what you are doing as a whole and everyone agrees with you, I think it is valid.

In the above excerpt, Megan pointed out the role of peer review in legitimating scientific knowledge (Figure 5.10). According to Megan, for a scientific claim to be validated, you should share your claims with others and others should run the same experiment and reproduce the identical results. A crucial reason why others should review your work is to decrease your personal bias and eventually to increase the objectivity of your claims.

> I think so, because if you, let's say devote your all life to this research project, then you may believe what you are doing is valid because you want to believe that it is valid. You want to believe that all the time and hard work you put into it is paying off and progressing in a positive direction. So I think if you are the only one to judge your own work it's kind of a biased opinion. So I think you need outside influences and outside opinions and people to be honest with you to make sure you are on the right path, on the right track. That's why, I think it's important.

According to Megan, peer review increases the objectivity of claims as well as adds content to the claims from different perspectives. Scientific collaboration reduces the possible bias proposed claims may have.

Megan reported that science is supposed to be objective, because it is universal. However, she added that, because it is difficult for scientists to be aware of their everyday life experiences, science is not generally completely objective. She said:

> I think it is supposed to be objective, because it is a universal subject. It is supposed to be unbiased so I think it is supposed to be objective. I think a lot of times it is, but I don't think it is possible not to have some certain other elements influence a piece of work. I mean, work done in the United States should be able to be understood same in China, because it is science and it is a universal language. But you know, it's hard for the scientists not to let their everyday stuff influence their work. It is not supposed to, but I think, that it is almost impossible to not bring other areas into your own work.

Megan agreed that scientists' personal worldviews and their everyday life experiences might influence scientific practice (Figure 5.10). She reported that scientists' values were influential in how scientists go through their investigations rather than in how they generate their conclusions. The design and planning stages of a scientific investigation are vulnerable to scientists' values (Figure 5.10).

Megan defined scientific facts as claims being accepted by the majority of people through peer reviewing (Figure 5.10). She used the words “peer review” and “scientific community” to describe how scientific claims are legitimized. She said:

> Scientific fact is something that has been peer reviewed, that has been accepted by the scientific community and by people who are able to understand it. That’s agreed upon by the majority of the people, I think, then it is considered as fact after that.

When asked, Megan responded that science was a social activity. However, she was still in favor of defining science as an objective entity. When she realized that her responses were contradictory, she explained her perspective as follows.

> I am not one hundred percent either way, because a lot of times the science that I do in our labs as a student is objective. There is one answer. You are supposed to get this answer. It’s being done a million times, you know, you are just doing it to get experience. It’s not like I am really going to discover something. But I think science done by people who are searching for different answers, that can become subjective, because that’s when their work can influence what they are doing. It is both ways. In all of my labs I have ever been in for a class, I’ve never gotten a result that they haven’t seen before.

In the above excerpt, Megan is saying that in conventional science education labs, because students are asked to find the correct results, science is often portrayed as completely objective. However, when you try exploring an unknown result, you will likely realize the extent to which science is *subjective*. Her claim is particularly important to note here, because it mirrors the consequences of conventional science classrooms and traditional laboratory activities. Being informed that, “There is one answer. You are supposed to get this answer” leads students to think that science is objective.

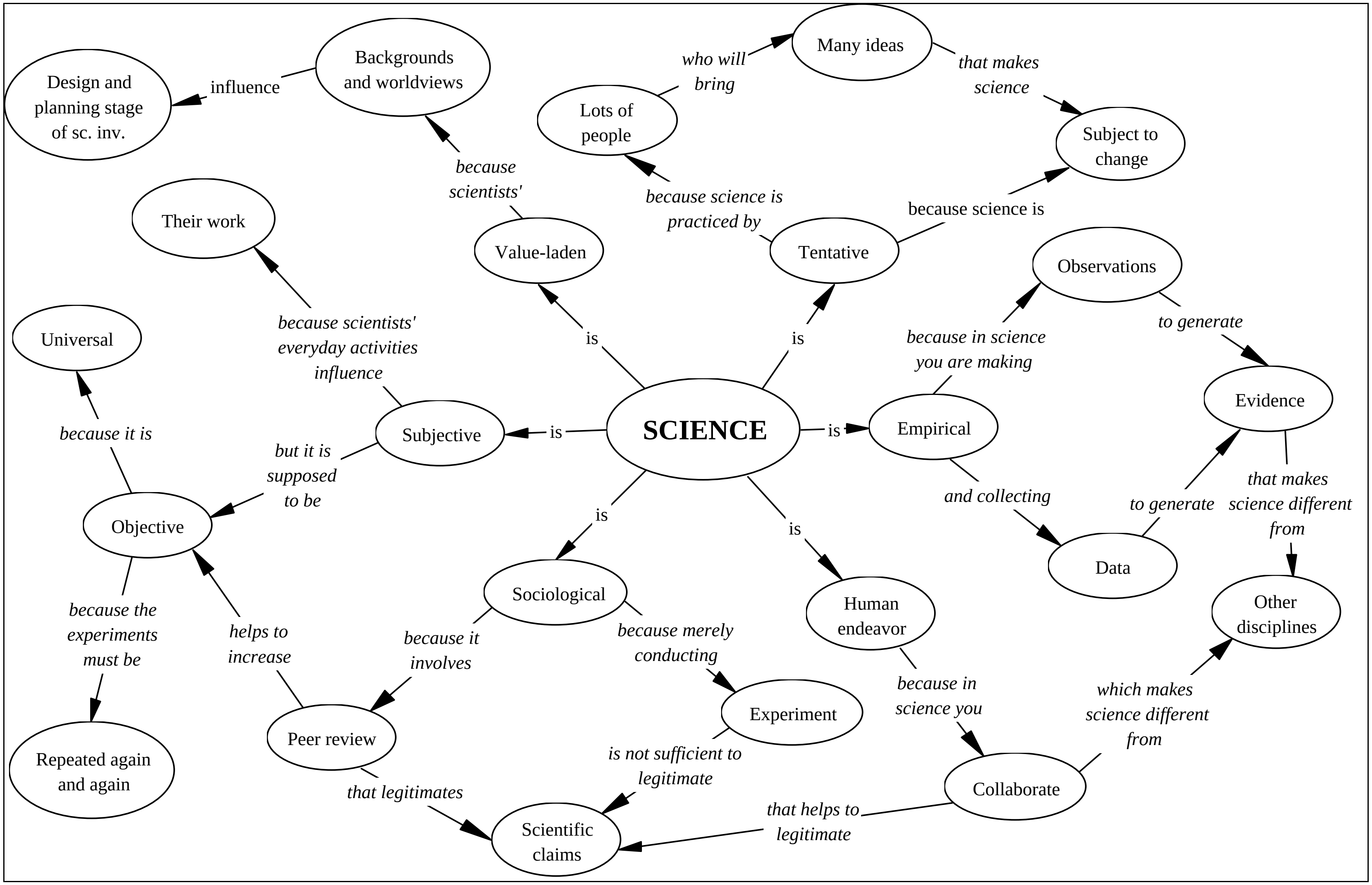

Figure **5.10**: Megan’s Post-conceptions of the Nature of Science.

5.2.6.4 Triangulation of the Interview Findings

In this section, I attempt to validate my interview findings using Megan's written responses to the philosophy of science questionnaire. There are two parts in this section. The first part is the comparison of Megan's understanding of the NOS, derived from the pre-interview findings, with her understanding of the NOS, derived from the pre-questionnaire findings. The second part is a comparison of the findings from the post-interview and the post-questionnaire.

Part I

In this part, I compare how Megan defined (a) science as a way to explore the world, (b) the *tentative* characteristic of science, (c) the objectivity of science as a distinctive characteristic, and (d) how scientists' personal views and backgrounds influence the design and planning stages of a scientific investigation.

In the pre-administration of the philosophy of science questionnaire, the definition of science, Megan provided was:

> Science is the study of the world, focusing on how and why it works the way it does. Science involves questioning, experimenting, revising, and concluding.

In the pre-interview, Megan defined science as "everything around us" and an activity of "thinking a lot, like questioning, exploring, and experimenting." What these definitions have in common is that, Megan perceived science as a way to explore the world through questioning and experimenting.

In the pre-questionnaire, Megan described science as "a work in progress," implying the progressive nature of science. She also implied that the world was constantly changing and so were the scientific facts. In both the pre-interview and pre-questionnaire, Megan responded that scientific claims were *tentativ*e, and they changed as the physical existence of the universe changed. This perspective is consistent with her belief that scientific facts are the physical reality, and no matter whether human beings exist on the world, these facts would still exist (Figure 5.9).

In the pre-interview, Megan took the position that science should be objective, because, this is what distinguishes it from other ways of explaining the world. The *empirical* nature of science was described as a distinctive characteristic of science (Figure 5.9). In the pre-questionnaire, Megan wrote:

> I think science has been labeled as 'objective' because that is the only way accurate, consistent results can be formed. If a person allowed his personal beliefs, wants, reputation, etc to come into play, then one could call science a biased subject. However, just because science is supposed to be objective does not mean that it always is. There are always personal agendas. Research deadlines, monetary rewards, reputation boosters, etc. that influence scientists to form certain conclusions. I do not believe this is the majority of scientists, but I do think this plays some part in the scientific research. From an educational standpoint, I think we need to teach our students to be objective, but not to totally leave ethics stranded. With the advance in technology, many new procedures are possible, and like it or not, ethics must be involved in order to make sure science doesn't get out of control.

Megan did not reject the influence of human values on scientific practices. But, according to Megan, human values only influence the way scientists approaches their investigation, not the conclusions they derive from the scientific observations. This view was repeated both in the pre-questionnaire and in the pre-interview (Figure 5.9).

Part II

In this part, I compare how Megan described (a) science as a process of active involvement, (b) the *tentative* characteristics of science, (c) the essence of collaboration and group work in science, (d) the objective nature of scientific claims, and (e) the *subjective* NOS.

In the post-administration of the philosophy of science questionnaire, Megan described science as a process: Active participation in doing scientific investigation. She wrote:

> Science is the process of establishing hypothesis, gathering data, conducting experiments to test the hypothesis, and arriving at either revised conclusions or reinforced conclusions. Science involves questioning the world and its processes, while making connections between it all.

In the post-interview, Megan also described scientific practice as engaging in finding, gathering data, experimenting, and drawing conclusions. These two definitions of science are similar.

In the post-questionnaire, Megan wrote about the *tentative* characteristics of science as follows.

> Science is in a constant state of uncertainty. There is always the possibility of disproving or refining a common held theory based on the introduction of new information and the creativeness of a different scientist.

In the post-interview, Megan also mentioned that science was *tentative* and subject to change, because science was practiced by many people all of whom contributed many ideas (Figure 5.10).

In the post-questionnaire, Megan reported that group work and collaboration were crucial in science. She wrote:

> I certainly think group work in all subjects is important to establish the basic skills of cooperation, patience, and listening. However, science is such a collaborative area of study that has become dependent on group work and the sharing of data. I think that science is very much a subject that can be interpreted in many different ways depending on the person's scientific background. Misconceptions are held by everyone, even scientists, and when people are allowed to discuss these things, the misconceptions are cleared up and everyone involved learns something new. I think that in science, scientists talk and share research findings with each other much more often than students in science classrooms do. Peer reviews also take place in science, where the teacher is usually the main evaluator in a classroom.

In the post-interview, Megan also pointed out the role of collaboration and group work in science (Figure 5.10). In the above excerpt, Megan talks about peer review in science and how a conventional science classroom lacks that aspect. According to Megan, if students learn things on their own, they will understand the concept better than if they are lectured to. In the post-questionnaire, Megan wrote:

> I think that by allowing students the chance to learn things on their own, via group work or in the lab, they will understand it better than if a teacher just lectured about it.

In the post-interview, Megan often mentioned the role of group work and the collaborative nature of science (Figure 5.10).

In the post-interview, Megan discussed her argument that science should be objective, even though, it is often subjective (Figure 5.10). She provided a similar argument in her written responses to the post-questionnaire items. She wrote:

> I think it (objective nature of scientific practice) has become such a tradition in science because it is the only way science can be viewed as factual, consistent information, regardless of the types of people conducting the research. Since science is a universal subject, the results of an experiment in Europe, for example, must be able to be reproduced in another country. This would mean that the same results should be concluded. The differences in race, religion, economic background, etc. are irrelevant in science. In reality, however, some people adhere to personal agendas and allow their opinions to interfere with research.

In the above excerpt, Megan does not deny the *subjective* characteristic of science. However, she argues that scientific conclusions should be objective because this is what makes science universal. She made the same argument in her post-interview. She told me that science was subjective, because scientists' everyday activities influence their practice, even though, the goal is to be objective (Figure 5.10).

The comparisons above show that Megan's understanding of the NOS, as I derived from the two instruments, are consistent with each other.

5.2.6.5 Changes in Megan's Conception of the NOS

Megan's responses in the pre-interview and post-interview were similar with regard to the *subjective, tentative, empirical*, and *value-laden* characteristics of science. After the CPR project was completed, Megan added the *sociological* and *human endeavor* characteristics of science to her portrayal of science. In the post-interview, she often referred to peer review and the collaborative nature of scientific practice.

In the pre-interview, Megan said that science was *tentative*. The reasons she gave were that, the physical existence of the universe was constantly changing and there were a lot things that human did not yet know (Figure 5.9). In the post-interview, she reported that science was *tentative*, but this time her explanations were different. She did not tell me that physical reality was changing and because of this science was *tentative*. She rather said, because science was practiced by many people, who brought many ideas from different perspectives, scientific claims were subject to change. Megan was indicating the collaborative nature and the group work characteristics of scientific practice in explaining the *tentative* tenets of science, after she participated in the CPR project.

Megan continued to hold the same conceptions of the objective and the universal characteristics of science, after the CPR project. She also did not change her views on the *empirical* characteristics of science and how these made science different from other ways of knowing the world.

Megan discussed the *sociological* and *human endeavor* characteristics of science during the post-interview (Figure 5.10). She pointed out the need for group work and the collaborative aspect of science. Megan talked about peer review in scientific practice. She stated that peer review helped legitimize the scientific claims that might not have been solely legitimized through repeated experiments.

In the pre-interview, Megan said, in order to legitimate the scientific claims one should do “personal research” and others should agree with the results of this research (Figure 5.9). For others to agree with these scientific claims, they should have done the same experiment. In the post-interview, she pointed out the role of peer review in scientific practice. She stated that experimenting was not sufficient to validate scientific claims (Figure 5.10). A mutual agreement among peer reviewers should be established for these claims to be legitimized.

In the post-interview, Megan provided another perspective on the collaborative nature of science. She said science was a *human endeavor*, because it required group work and collaboration, which were cited as two distinctive characteristics of science from other fields of inquiries, e.g., religion (Figure 5.10). Megan’s argument that science requires social interaction (group work & collaboration) is parallel to the collectivization characteristic of science (Ziman, 198), which is a sociological perspective of science.

5.2.6.6 Megan's Experiences with the CPR Project

Megan particularly liked the original research aspect of the project. According to Megan, not all the students had complete data from their experiments. Megan found the peer review aspect unique because of its on-line and anonymous aspects. Grading one another's work was another remarkable component of the project. Megan agreed with her peers' review of her work, made the revisions they suggested, and learned from them. She also said, her final published report was improved, after she made the revisions that she would not have thought of doing otherwise. Megan would consider using a similar peer review with her students in the future, but she was unlikely to allow students to grade one another's work.

Next, I explain Megan's experiences with the CPR project, illustrating her responses to the interview items. I used the Semi-structured CPR Interview Protocol (Appendix C) to explore Megan's experiences with the project activities. I also utilized Megan's quantitative responses from the final student questionnaire (Appendix F) in describing her experiences.

Megan liked the original research aspect of the CPR project, particularly the freedom to choose the chemical that was to be tested for its toxicity.

> I liked how it was an open ended assignment, and for once we were able to choose our variables. We were able to kind of create our own experiment within the bounds of the goals of what we were supposed to learn. I think, that was fun, because we can choose any substance, we can use a variety of different seeds, and you know, pretty much the procedure was the same, but the variables were up to us.

Megan did not report any concerns about her experiences with the CPR project. She pointed out that not all the students might come up with a complete set of data.

> Umm, the hard part, I don't think I didn't like it, but the hard part was that it was done only one time. I mean, it was done one time on a bunch of different plates, but a lot of people, not really my group, but a lot of people didn't get any data for some of it and they didn't know if it was because they did something wrong, or it was too toxic, or because it was only done once. So they don't know f they were accurate results.

Megan found the peer review aspect of the project unique. She had never done an on-line peer review prior to the CPR project. In her previous peer review experiences, the instructor (a teacher or a teaching assistant) was the only person who graded her written report.

> Probably to publish it [was unique]. We had to write a lab report, hand it in, and I guess get it graded by one person. Then, and you know, it gets handed back, and that's it. But this one was not like that.

> Teachers and the TA's review it [the reports written in a project other than the CPR project]. I think maybe once or twice we had it reviewed by a peer in class and then we handed it in, but it wasn't like [the CPR project], it was still graded by one person. But in this one [the CPR project], you got to use this group thing, so it was a pair thing, but you had to publish your own report and interpret the ways that you want to do it. I don't know if my partner interpreted the data as I did. We got the same data, but we could have interpreted it in two different ways. So that was neat, I mean being able to work individually, and then publish it, this was neat. So I got reviewed by two people and I got the opportunity to think about it differently. Then you go and publish it. That's how it was different.

Megan told me that the peer review in the CPR project was similar to how peer review was done in science.

> It was neat to have someone like other people in the science education area, take your work seriously. It was seriously peer reviewed. People respected what I have to say, and they acted like scientists because this was our own individual creation. We decided what to use in it and we interpreted the way that we wanted it. We put it up there to be criticized, and let people do whatever they wanted to do with it.

In the above expert, Megan describes that students in the CPR project enacted as if they were scientists. Below, she further elaborates students' roles in the project and explains why their practices were authentic.

> The collaborating, the peer review thing was major. We learned about how scientists get peer reviewed. All the time in my science classes it's always graded by a teacher or TA. It's not one of peer reviewed ones. It's not done like that even though that's how science is supposed to be done. We never did that so that's why I thought this [peer review in the CPR] was neat because it was actually done the way science in the real world is usually done.

Megan responded positively that she agreed with her peers' evaluation of her work. She said that one of the reviews she received was not providing plausible interpretations and it was inconsistent with the scoring. However, she did not find this problematic, because she thought this was usual and could happen in real science.

> Ah, yes, pretty much [I agreed with my peers' evaluation], There was one person, I don't know who he was, that person kind of suggested that his or her interpretation of my work and my interpretation of the data were two different things. So I don't know if that affected their evaluation of me, but we had different opinions as to why things happened the way they did. So I don't think that is a problem. I think that's part of science. You are never going to have everyone agree with you.

In the final student questionnaire, Megan reported neutral (scored 3 out of 5) to the item: "the quantitative scores I received from peer reviews were fair."

Megan found the reviews helpful. She gained a broader perspective based on the reviewers’ comments.

> Yes, I did [learn something new from the reviews]. One thing they said, I agreed with it, but I haden’t thought of it, was just an example that reinforced me to think how important other people’s input is. I might not, I might have not even thought of it, you know, it was not even in my part of my protocol or anything.

Megan reported that the quality of her on-line published report was improved after the peer review.

> I think I improved it because right after I did my peer review to others, it was the chance to see other people’s work and how they did the lay out and how much they get into details in certain sections. So I made sure that it was consistent with those. For example, detail wise pay attention to how much time I spend on it. So I added some line based on what this person did. I suggested that maybe this could be another reason why, for example I didn’t say this is why this happened. I just said another idea could be because what this person said really made me think. I didn’t really know which one was right, but it could be combination, it could be combination of one or the other. So I think it helped me get more conclusive.

In the final student questionnaire, Megan strongly agreed (5 out of 5) that peer review helped her to think more critically and improved her scientific writing (see Appendix F for the questionnaire items and participants’ responses).

Megan told me that she was unlikely to have made the revisions, had she not received the reviewers’ comments.

> No, I would have left it the way it was, because I did it once and nothing has changed since I did the last time. So I wouldn’t have changed it.

In the final student questionnaire, Megan reported strongly agreed (scored 5 out of 5) with the item: “I received useful peer review comments about my report.”

Megan said that she would consider using a similar peer review with her students when she begins teaching, but she might think about whether a similar project is appropriate for her students.

> Yes, I did think about it [using a similar peer review in the future] actually when we were doing it [the CPR project] because I think it will have to be the right kind of people, depending on the age.

Megan was neutral (scored 3 out of 5) regarding whether she would use formal peer review when she begins teaching. All other participants either agreed or strongly agreed with this item of the final student questionnaire (Appendix F). Megan was also hesitant that meaningful peer review was a reasonable expectation for college students as well as for high school students. She scored 3 out of 5, indicating that she was neutral on the issue of whether peer review was appropriate for college and high school students. All the other participants either agreed or strongly agreed with those statements.

Megan was concerned that K-12 students might not take the peer review seriously, especially when they grade one another's work. She said:

> Because I think people of certain age may not take it seriously or they not take it as constructive criticism, and they may get offensive. So I think they have to be mature enough to understand that it's a part of science. But I think it is important, because it is an accurate perception of what scientists do. So in some form I think it is important to include that in a science classroom. It could be any grade, like if you are teaching younger kids and, you know, what they say might not directly affect that person's grade they might be just their own. You know, they may just think this is their own, but in higher grades or in more important projects you can have what these people say to you can actually count towards part of your grade because it is counted for our grade like what those two peer reviewers did.

Megan expressed concern about younger children to grade in a peer review situation.

5.3 Cross-case Analysis

In this section, I compare and contrast (a) the changes in participants' understandings of the NOS and (b) students' experiences with the CPR project.

5.3.1 Changes in Participants' Conceptions of the NOS

In the pre-interviews, all five participants explicitly reported that science was *empirical, subjective,* and *value-laden*. Except Jacob, all participants also explained that science was *tentative*. Three participants (not Liz and Megan) described science as a *human endeavor*. In the post-interviews, all five participants reported science as *empirical, subjective, tentative, value-laden,* a *human endeavor,* and *sociological*. The changes in participants' conceptions of the selected NOS tenets are summarized in Table 5.1 and described below.

Table **5.1**: A Summary of Changes in Participants' Conceptions of the NOS.

Tenets of the NOS	**Frank**	**Cindy**	**Jacob**	**Liz**	**Megan**
Empirical	not changed	not changed	not changed	not changed	not changed
Subjective	not changed	not changed	not changed	not changed	not changed
Tentative	not changed	not changed	NA	not changed	not changed
Value-laden	not changed	not changed	not changed	not changed	not changed
A human endeavor	not changed	not changed	not changed	Changed	Changed
Sociological	Changed	Changed	Changed	Changed	Changed

In this study, I observed two major differences in participants' pre and post-test portrayals of science as crafted by interview analyses. The first difference is that participants added explanations of the *sociological* characteristics of science in their responses to the post-interview items. The second difference is that participants provided evidence supporting their arguments for the *subjective, tentative*, *value-laden* and *human endeavor* characteristics of science. In the post-interviews, participants often referred to the *sociological* NOS in their explanations of how and why science was *subjective, tentative, value-laden* and a *human endeavor.*

Four of the participants (not Frank) did not mention the *sociological* NOS in their portrayal of science in the pre-interviews. The collectivization of science, peer review, and how scientific claims are legitimized were not addressed in the pre-interviews. Frank, as being the only participant of this study with experiences in a research setting other than a conventional science classroom or laboratory, reported some understanding of the *sociological* NOS in the pre-interview. Another participant, Jacob, had also experiences in scientific research settings other than a conventional classroom; however, I suspect Frank's experiences were more influential, because Frank was making a living whereas Jacob was a student during their scientific experiences.

In the post-interview, Megan added to her portrayal of science that science involves peer review and through peer reviewing, scientists validate one another's scientific claims (Figure 5.10). In contrast to her claim in the pre-interview, in the post-interview, Megan reported that merely running an experiment is not sufficient to legitimate scientific claims. Liz also expressed a similar argument in her post-interview, that science involves a review process that results in helping to legitimate scientific claims (Figure 5.8). Frank also included the *sociological* characteristics of science in the post-interview. He said scientists negotiated through peer review and through these negotiations, the claims with the most reasonable and the logical data could be chosen as the scientific knowledge (Figure 5.6). In the pre-interview, Frank reported that group work would increase the objectivity of science whereas in the post-interview he said group work was essential to legitimate scientific claims.

Another facet of the *sociological* NOS is that in order to legitimate scientific claims, scientists use peer review and come to a mutual agreement.

In the pre-interview, Jacob claimed that the only way to legitimate scientific claims was “testing again and again” (Figure 5.5). After the CPR project was completed, Jacob did not advocate that “testing again and again” is the only requirement for validating scientific claims (Figure 5.6). In the pre-interview, Cindy did not talk about any process people might follow to validate scientific claims (Figure 5.3). In the post-interview, she told me that scientists did peer review in order to decide on the best answer among many, and through this process scientific claims were validated before being shared with the public (Figure 5.4). In the pre-interview, Frank reported that scientists use peer review in order to increase the objectivity of scientific claims (Figure 5.1). In the post-interview, he pointed out the collectivization of science (Ziman, 1983), and said that science could not be practiced by one individual isolated from the society (Figure 5.2). Frank added that peer review helps scientists to verify their scientific claims, even though it is not a perfect system, and often influenced by the interests of society.

Participants described the *tentative* characteristics of science differently in the pre- and the post-interviews. They did not change their positions, but they did use different evidence to explain why scientific knowledge, facts, and claims were subject to change. For instance, in the pre-interview, Megan claimed that the scientific claims were subject to change because the physical universe was changing and there were many things that humans did not yet know (Figure 5.9). After the CPR project, Megan's evidence for the *tentative* characteristics of science were changed dramatically. In the post-interview, she told me that scientific claims were subject to change because science was practiced by many people, who bring many ideas from different perspective (Figure 5.10). Another example is how Liz explained the *tentative* NOS. Liz did not provide any supporting evidence for why scientific claims were subject to change in the pre-interview. She only said that scientific claims were subject to change because of human nature (Figure 5.7). In the post-interview, she explained that scientific claims are changing because scientists review each other and change their arguments though the physical phenomena stay the same (Figure 5.8).

I could not capture Jacob's understanding regarding the *tentative* characteristics of science in the pre-interview. Therefore, I do not speculate on whether Jacob changed or kept his conceptions of the *tentative* NOS before and after the CPR project. I would only report his post explanations. In the post-interview, Jacob said that scientific claims were *tentative* because of the changes in people's ideas and the physical phenomena itself (Figure 5.6).

Participants' explanations were different in describing the distinctive characteristics of science from other fields of studies. Collaborative and social characteristics of science were dominant in their post explanation of the reasons why science was different from other fields of inquiries. For instance, in the pre-interview, Megan said that science was different from other fields because of its *empirical* characteristics. In the post-interview, she made a different claim; science was different (e.g., from religion), because, in science, you collaborate with your peers in order to legitimate your scientific claims. You could practice religion, in contrast to science, individually, because it is all about your belief system.

In the pre-interview, Liz differentiated science from other fields based upon the *empirical* characteristics of science; experimenting and its use of proof to validate scientific claims (Figure 5.7). In the post-interview, Liz did not make the same claim but she said scientists used peer review to legitimate scientific claims, and they often did this through communication (Figure 5.8). Cindy differentiated science from other fields based on its objective characteristics in the pre-interview (Figure 5.3). In the post-interview, she did not make the same claim. Rather, Cindy told me that science was as subjective as other fields, for instance religion, in which even the beliefs in contraception had been changing (Figure 5.4).

Participants varied in how they described the *human endeavor* characteristics in the post-interviews. Liz and Megan did not mention the *human endeavor* characteristics in their pre-interview sessions, but they did mention it in the post-interviews. In the post-interview, Liz added that science was a *human endeavor,* because it was done with many people and through collaboration (Figure 5.10). Liz pointed out that, communication among scientists to legitimate scientific claims reflects an understanding of the *human endeavor* characteristic of science (Figure 5.8). Regarding the *value-laden* tenet of science, Liz also mentioned in the post-interview that, science was *value-laden*, because it included human values which influence the decisions scientists make in peer review

(Figure 5.8). Cindy agreed that, science was a *human endeavor* in her responses in the pre-interview (Figure 5.3), but did not provide supporting evidence in reference to the *sociological* NOS. She only told me that science was a *human endeavor,* because people did it through communication (Figure 5.3). In the post-interview, she restated her argument and she told me that science was a *human endeavor,* because scientists first validated the scientific claims through communication and collaboration, and then shared them with the public, all of which were human activities that result in legitimating these claims (Figure 5.4).

5.3.2 Participants' Experiences with the CPR Project

In this section, I compare and contrast participants' experiences with the CPR project. Table 5.2 summarizes the participants' experiences as they are reported in the interview session. I also utilized participants' quantitative responses to the on-line final questionnaire items (see Appendix F for the questionnaire items and participants' responses) in explaining participants' experiences with the project activities.

All the participants, except Cindy, reported that they liked the original research aspect of the CPR project. The original research aspect was interesting for the students because they conducted scientific investigations in which the results were not known by any party, including the instructor. Students were free to choose the chemical they wanted to use in their experiments. This aspect of the project motivated students to get involved in their scientific investigations, because, it provided students opportunities to own their scientific results.

Table **5.2**: A Summary of Participants' Experiences with the Activities of the CPR Project.

Participants:	**Frank**	**Cindy**	**Jacob**	**Liz**	**Megan**
1- Mostly Liked	Original research & group work	Peer review	Peer review & original research	Original research	Original research
2-Least Liked	Lack of constructive feedback	Incomplete feedback	Quantitative scoring in peer review	Late reviews	Nothing
3- Unique	Original aspect	On-line peer review	Peer review	Peer review	Peer review
4- Will use it	Yes	Yes, but does not allow K-12 students grade one another.	Yes, but does not allow K-12 students grade one another.	Yes	Yes, but does not allow K-12 students grade one another.
6- Learned new things	No	Yes	Yes	Yes	Yes
8- Made changes	Yes	Yes	Yes	Yes	Yes
5-Agreed with comments	No	Yes	Yes	Yes	Yes
7- Improved after the review	No	Yes	Somehow; feedback was on grammar and spelling	Yes	Yes
8- Suggested	Eponymous feedback	Eponymous feedback & second time experimenting	Only qualitative feedback	Second time experimenting	Nothing

Cindy and Jacob expressed that they liked the peer review aspect of the project. Frank mentioned that working in groups was fun.

The lack of constructive and incomplete feedback was the main experience participants disliked the most. Liz expressed concern that she received her review late. Jacob did not find the quantitative scoring of his report valuable. He thought, the scores he received were not meaningful and did not help him to improve the quality of his report.

Four of the participants found the on-line peer review aspect of the project unique. Even though, some of them had experiences with peer reviewing in other classes, they had never done an on-line and anonymous peer review before. Frank mentioned that the original research aspect was new to him. That is, he had never done an authentic scientific experiment in class where the results had not been known by any of the parties.

In the interviews, all of the participants of this study responded positive that they would use a similar peer review system with their students when they begin teaching (Table 5.2). This is also evident in participants' responses to the final student questionnaire items (Appendix F). The average rating of participants' responses to the questionnaire item: "If I taught science, I would like to us some type of formal student peer review" is 4 out of 5, indicating that overall, they would use similar system when they begin teaching. Participants also reported that meaningful peer review was a reasonable expectation for college students as well as for high school students (average ratings were, respectively, 4.6 and 4.0 out of 5). In the interviews, Cindy, Jacob, and Megan reported that they would not allow their students to grade one another's report.

They expressed their concerns that students in lower grades might not be mature enough to thoroughly evaluate others' work and assign fair grades.

All the participants, except Frank, told me that, the reviews they received were instructive (Table 5.2). This is also evident from participants' quantitative responses to the final questionnaire items (Appendix F). Liz, Jacob, Cindy, and Megan scored 4 out of 5 for the item "I learned something by writing peer review comments" indicating that they agreed with that item. Frank scored this item 3, indicating that he was neutral that he learned something new.

Frank also scored the item: "I received useful peer review comments about my own report" in the final student questionnaire (Appendix F) with a much lower rating than the other participants. Frank strongly disagreed that he received useful comments (scored 1 out of 5). Liz and Megan scored that item 5, indicating that they strongly agreed that they received useful peer review comments. Jacob and Cindy responded to the same item with a slightly lower rating but still positively; they scored 4 out of 5, indicating that they agreed that they received useful peer review comments.

Interview analysis revealed the similar findings. All participants, except Frank, reported that they agreed with their reviewers' comments. Even though, Frank thought he did not agree with the reviews and did not learn anything new from them, he still made the suggested changes as did all the other participants.

Frank said, his report was not improved, after he made recommended changes. Jacob was neutral regarding whether his final on-line published report was improved after he made the suggested revisions. He pointed out that the suggestions he received related to grammar and the spelling of the written text but not to the quality of the scientific reasoning or the logic. Cindy, Liz, and Megan reported that their reports were improved when they made recommended changes that they would not have made otherwise (Table 5.2).

When the final student questionnaire responses (Appendix F) are examined, it can be said that Liz, Cindy, and Megan were in favor of using anonymous feedback in reviewing one another's reports. Frank was neutral that it was easier for him to review reports of those whose identity he is unaware of. Jacob disagreed that anonymous feedback made him feel more comfortable reviewing others' reports.

During interviews, participants suggested that, if the peer reviews were not anonymous, students would provide more constructive and concise feedback. Jacob strongly recommended deleting the quantitative scoring from the system and only including the qualitative feedback (Table 5.2). This is also evident in his final student questionnaire responses (scored 2 out of 5, see Appendix F). In the interview, Jacob argued that allowing reviewers to provide only qualitative feedback would eventually increase the quality of the feedback.

Liz and Cindy made a recommendation for the experimental procedure. During interviews, they told me that allowing students to run the same protocol again after they received feedback on their first on-line report would help them to thoroughly understand their investigation and come up with better results.

Chapter 6

Conclusion, Implications, and Future Recommendations

In this chapter, after summarizing the research findings, I discuss the motivation for this study and its importance for the literature. Next, I present the limitations of the present investigation followed by implications to science education and suggestions for future research.

6.1 Summary of Findings

This study provides evidence that an implicit and contextualized Nature of Science (NOS) instructional strategy can help students to develop an understanding of the sociological NOS. This conclusion is based on the changes in participants' portrayals of science. Table 5.1 shows that after students completed the activities of the College Peer Review (CPR) project, they viewed scientific knowledge as socially constructed.

In the pre-interviews, all five participants in this study reported some understanding of the empirical, subjective, tentative, and value-laden characteristics of science; however, they did not demonstrate a solid understanding of the sociological NOS. In the pre-interview, only one participant, Frank, expressed a moderate understanding of the sociological NOS (Table 5.1). Frank, unlike the other participants, had experiences in scientific research settings other than conventional science classrooms or laboratories. After the participants completed the CPR project, their understanding of the sociological NOS dramatically changed whereas their position on the aforementioned tenets of the NOS remained constant. The CPR project, through its original research, peer review, and on-line collaboration aspects, led students to appreciate the social characteristics of science and the sociological NOS. In the post-interviews, students talked about the sociological characteristics of science in their portrayal of science. Students also provided evidence from social constructivist and relativist orientations to explain the subjective, tentative, and value-laden characteristics of science, which they recognized as a human endeavor.

This study also explored participants' experiences with the project activities. Findings revealed that students found the peer review and the original research aspects of the project unique and interesting. Students enjoyed working in groups and the on-line collaboration. Some of the participants reported that the CPR project helped them a great deal to see how real science was practiced. Some students said that the CPR project showed that "testing again and again" was not the only procedure scientists follow in validating scientific claims, knowledge, and facts.

6.2 Study Findings and the Nature of Science Literature

Participants' NOS understandings reported in the pre-interviews were in line with the expectation of the NOS education literature. Study participants viewed science as empirical, tentative, subjective, value-laden, and a human endeavor. Some also explained that science is theory-laden, not always progressive, has falsiability characteristics, and evolves through paradigm shifts. These views of science are desirable and do not require remediation based on the current NOS education literature perspectives that I reviewed earlier in this study (e.g., Lederman, 1992; Matthews, 1996; Matkins, et al., 2002; and Schwartz, et al., 2000). In addition to the basic tenets of science (i.e., empirical, theory-laden, subjective, tentative, value-laden, and a human endeavor), participants of this study also reported elements of arguments that can be found in the philosophy of science literature (e.g., falsiability- Popper, normal versus revolutionary science-Kuhn). In that regard, the study participants' views of science were advanced and did not require remedy. However, the social constructivist and Sociology of Scientific Knowledge perspectives were not included in the participants' portrayals of science before they participated in the CPR project.

Many of the NOS studies I reviewed earlier in this study did not pay sufficient attention to the sociological NOS. Even though they often used the phrase "socially constructed" and referred to science as a social entity, they did not describe the details of what is socially constructed and why science is a social entity. "Science is a social entity" is just a sentence that anybody can use. However it does not necessarily refer to scientific knowledge-generating processes. For example, noting that scientists interact with each other -- talking, sending emails, working together in a lab, collaborating in investigations, etc. -- does not directly address the social construction aspect of scientific knowledge generation. The problematic part is that even if students say "science is socially constructed," they may still believe that the only way to verify a scientific claim is "testing it again and again." If the experimental results always lead to the same conclusions, then students are going to accept that knowledge claim as true. Otherwise, they will not consider it as legitimate, valid knowledge.

Science does not demand any social interaction if “testing again and again” is regarded as the only requirement for accepting the validity of a scientific claim. Therefore, if students believe “science is socially constructed” and also claim that “testing again and again” is the only way to validate information, I would consider their “socially constructed” perspective of science highly superficial. Indeed, students often describe the social characteristics of science as scientists talking to each other, communicating, and collaborating. They do not recognize that scientific knowledge is also generated through negotiation and mutual engagement. This is a particularly important distinction that is not addressed in many science education studies.

After the CPR project, students reported similarly about the NOS tenets except that they added the sociological NOS perspective to their portrayals of science. They maintained that the knowledge generated through scientific practice has social aspects. They no longer asserted that the means of validating a scientific claim is “testing again and again.” These views are consistent with both the NOS education literature and the Sociology of Scientific Knowledge and social constructivist views of science that I reviewed earlier in this study.

6.2 Discussion

I started this dissertation with an explanation of my views of science teaching. I stated that I perceive science teaching practice as comprised of two separate but relevant parts. The first is teaching about the scientific knowledge as subject matter and the second is teaching about the philosophical, sociological, historical, and anthropological perspectives of science. I find it particularly helpful to categorize science teaching into two separate but coherent parts because I believe the strategies instructors employ to teach these parts should differ.

In Chapter 1, I maintained that because of the nature of teaching scientific knowledge as a pedagogical act, science educators unintentionally promote a belief that there is one explanation of the phenomenon under investigation. No matter how students learn scientific knowledge and its methods, they all try to learn what the current scientific paradigm proposes as true and valid. When we teach science, we presume that there is one explanation for the concept we teach, and we design our teaching strategies based on that assumption. For instance, in the Conceptual Change Strategy (Posner, Strike, Hewson, & Gertzog, 1982), the intention is to change students' alternative conceptions into scientifically correct conceptions. In teaching through inquiry, students are asked to follow a scientific method that leads them to uncover a concept that the prevailing scientific paradigm believes to be true. My focus in this study is not whether there are one or multiple explanations of a phenomenon. Rather I argue that it is crucial to emphasize that assumption especially when teaching about the philosophical, sociological, historical, and anthropological perspectives of science.

In Chapter 2, I attempted to prove that there is no one best philosophical or sociological explanation of science. I retrospectively summarized the major philosophies of science, which have shaped our current understanding of science and its enterprise. The summary shows there is no one philosophy of science on which everybody agrees. In addition to the existing skepticism regarding one dominant philosophy of science, Sociology of Science Knowledge (SSK) introduces another dimension to the discussion.

According to SSK, scientific knowledge is socially constructed. This contrasts with the logical positivist view of science, which has given rise to current science teaching strategies.

I am comfortable with the fact that there are multiple philosophical and sociological explanations of science, and I do not feel a need to support a particular perspective. In the literature, many researchers also mentioned that they were comfortable with the multiple explanations of science and they did not find it problematic (e.g., Kelly, 1997). If there is no one best explanation of science, then how are we going to teach students about the philosophical and sociological perspectives of science and which strategies do we use?

We should not use the same strategy to teach the philosophy, sociology, history, and anthropology of science that we use to teach scientific knowledge. In teaching philosophy, sociology, history, and anthropology of science, we have to allow for multiple perspectives.

A goal of science teaching is to help students acquire scientific knowledge and make them scientifically literate (AAAS, 1996). To achieve this goal, science educators employ different strategies, all of which derive from various learning theories on effective teaching. In this study, I did not focus on teaching about scientific knowledge. Hence, in my analysis, I did not assess students' performance regarding scientific knowledge.

Modern societies do require individuals to be informed about some sort of scientific knowledge; best asserted by "Science for All Americans" (AAAS, 1996). Of course, I agree that new teaching strategies and methods should be further investigated to illuminate their effectiveness. However, I have a different view regarding the teaching of the philosophical, historical, sociological, and anthropological perspectives of science. I do not believe that we should teach one particular philosophy or sociology to students.

Teaching about the philosophy of science is best addressed with the term; the Nature of Science (NOS), in recent science education literature. Lederman (1992) describes the NOS in terms of the values and assumptions inherent to the development of scientific knowledge. Hence, a person's understanding of the NOS is her beliefs about science and its enterprise. These beliefs include but are not limited to whether science is amoral, tentative, empirically based, theory-laden, parsimonious, subjective, value-laden, or a product of human endeavor or human creativity.

When we talk about the philosophical and sociological explanations of science, we mean the values and assumptions inherent to the development of scientific knowledge. Therefore, talking about philosophical, sociological, historical, and anthropological assumptions about science corresponds with our understanding of the NOS. Hence, in this study, I have assumed that NOS, or a person's understanding of the NOS, are consistent with her philosophical and sociological understanding of science. Even though, most researchers argue that it is dogmatic to expect students to develop philosophical connotations, in order to explore the underlying assumptions of the NOS and their impact on the employed teaching strategies, we need to address the philosophies of science. Therefore, I believe our intention in teaching NOS should stem from our understanding of philosophical, sociological, historical, and anthropological perspectives of science. In this study, I focused on the philosophy and sociology of science, even though, I believe there may be other perspectives, all of which will eventually enhance our understanding of science.

In search of an appropriate NOS instruction, I argue that any strategy implemented should be ideologically neutral, meaning that the instruction students receive should provide them with opportunities to develop their own understandings rather than simply asking them to acquire a predetermined set of perspectives or a particular world view regarding science. If we assume that every teaching act has a pedagogical connotation regardless of our belief that we should be ideologically neutral, then how can we teach about NOS? The literature discusses four basic strategies for teaching the NOS (Table 2.1). I advocate teaching NOS through an implicit and contextualized strategy as opposed to one that is explicit and decontextualized. An explicit NOS teaching strategy promotes the idea that there is one best philosophical (and also one sociological) explanation of science. Making the instruction decontextualized encourages students to repeat, in the sense mimic, in the exact way they are being taught. An explicit and decontextualized NOS instructional strategy corrodes students' potential ability to reflect upon their experiences and generate ideas, and more apparently situates their conceptions and attitudes. From the very beginning, an explicit and decontextualized NOS instructional strategy gives students no opportunity to develop their own understandings. Such a strategy has potential vulnerability especially when we teach about a philosophical and/or sociological perspective. We should not consider our philosophical and sociological perspectives of science to be the best explanations that students should also adapt. We should not simply transmit our understanding to students as though NOS instruction is an organized religion. Because, I believe, in teaching the philosophical and sociological perspectives of science, we should be ideologically neutral and not simply transmit what we believe as true.

This study used an implicit and contextualized NOS instructional strategy and explored its effectiveness in helping students understand the NOS. The aim of instruction was not to simply transmit predetermined NOS perspective but to lead students to engage in authentic scientific investigation with the hope that they would develop their own understanding. Research findings I reported in Chapter 5 are the observed changes in participants' conceptions of the NOS. These findings provide evidence that such a strategy can lead students to develop sociological NOS, which may also be considered the overall goal of the teaching act.

6.3 Limitations

This study has several limitations related to the nature of the participants, how they were selected, and the methods used.

First, all the participants were college students, making it difficult to generalize these findings to all students. In this study, based on my findings, I claim that an implicit and contextualized NOS instruction strategy can be utilized to teach about the sociological NOS. However, the same strategy may not be effective with a group of students in different grades, who have an incomplete understanding of or unfamiliarity with the basic tenets of the NOS. The participants of this study were pre-service science teachers enrolled in a science education program in a Northeastern research university in the USA. Students enrolled in this program are often exposed to the basic tenets of the

NOS through their education. As such, participants of this study had taken science education courses prior to the CPR project, and thus they were exposed to most of the basic tenets of the NOS in many different ways. It is also evident that, in the pre-interviews, participants expressed an adequate understanding regarding the empirical, tentative, subjective, value-laden, and human endeavor tenets of the NOS. The sociological NOS was not discussed by the students in the pre-interview. If the same study is performed with other students who have a different understanding of the basic tenets of the NOS, findings may not be similar. Students with little or no exposure to the basic tenets of science may not thoroughly understand and comprehend the similar activities. Students may develop different understanding of the NOS or the CPR project may have no effect on their understanding. However, exposing students to the peer review and the original research aspects of the project still has the pedagogical value of showing students how real science is practiced.

Another limitation of this study is the participants' willingness to work with me and their motivation to learn about the NOS. Participants were excited to talk about the issues I presented during the interviews. Their enthusiasm was not a coincidence. Because I invited students to participate in this study, and have intentionally chosen five of them, the study participants were intrinsically motivated and willing to participate. If this study were performed with a group of students at the same level but without motivation and willingness to participate, the findings might not be similar.

All research has limitations because of the research methods employed. In this study, I collected the primary data through interviews. In qualitative inquiry, the investigator interprets the collected data and reports her understanding of the data analyzed. Hence, the research findings will eventually include the investigator's bias. In order to reduce investigator bias, I included detailed descriptions of the interview sessions and illustrated my categorizations with excerpts directly taken from the interview conversations. I am aware of the fact that a completely objective interpretation of qualitative data is unachievable. Therefore, readers should consider that the findings reported in this study are partially based on my interpretation of participants' responses. Other researchers may interpret the findings of this study differently.

Another methodological limitation concerns the triangulation of the research findings. I used the philosophy of science questionnaire to triangulate my interview findings. There are other ways to triangulate qualitative data findings (Denzin & Lincoln, 2000; Glaser & Strauss, 1967). I could have asked participants to report on my interpretation of their responses, but because of the time limitations, I was not able to do that. In similar studies, investigators should consider asking participants about their interpretations. Peer review is another method of performing triangulation of the qualitative findings. Future investigators may want to triangulate their findings by asking a third party to perform similar qualitative analysis and compare their findings.

Another limitation of this study is the potential for misunderstanding because my native language is not English. In transcribing interviews, I made some mistakes that a native speaker would likely not have made. However, to identify problem areas, I received help from both my Ph.D. advisor and a professional transcriber whose native language is English. With their assistance, I addressed areas where my English language skills may have let do errors in transcription. Throughout this process, care was taken to make sure that confidentiality agreements with the interviewees were not violated. The transcriber expert did not watch the videotapes or listen to recordings that might make interviewees' identities explicit to her. Instead, she reviewed my verbatim transcripts and pointed out possible errors I might have made. With her concerns in hand, I listened the tapes once again, and checked for transcription errors. Asking a native speaker to read my transcripts was particularly helpful to me, because it easily identified mistakes that jumped out in context. For example, in one instance, I had erroneously transcribed the word "releasing" as "realizing" and in another instance I substituted "under related" for "interrelated."

Another limitation relates to the fact that I was not an outside researcher but rather an assistant in the class from which study participants were drawn. I was assisting Dr. Carlsen, the SCIED 411 course instructor, and students knew about me and my status before and during the investigation. If I were an outside researcher (with no connection to the course instructor), students might have responded to my interview questions with less concern that their responses might become known to the course instructor. To alleviate these concerns, I assured students that their responses would not being shared with the course instructor until course grades were submitted, and that their decision to participate or withdraw would have no effect on their course grades or credentials within their programs.

The SCIED 411 course was a science teaching method course taught by Dr. Carlsen. In the Science Education department at Penn State, all of the instructors and the teaching assistants are well informed about the NOS and the importance of teaching it. Students come across the NOS tenets either directly or indirectly through their studies. Although Dr. Carlsen did not explicitly teach NOS tenets, students were asked to read the course textbook and other materials that included sections devoted to the NOS. In interviews, some participants in the study mentioned the “falsiability” idea of Popper and the “normal versus revolutionary science” thesis of Kuhn. Students might have changed their conceptions based on what they had read before or during the study semester. However, much of the material discussed in the textbook was not the focus of this study. For example, students’ views about the subjective and empirical NOS, which were addressed in the course textbook showed little change.

In this study, I build a theoretical framework derived from the philosophy of science and a sociological perspective of science; SSK. I did not include the historical and anthropological perspectives of science in the theoretical framework. The historical perspective of science is partially included in the contemporary definition of the NOS; such as science is tentative, that is, scientific knowledge is subject to change based upon new discoveries or a shift in existing paradigm (Kuhn, 1962). The anthropological perspective of science is almost unaddressed in the theoretical framework of this dissertation. I am aware that this study omits the anthropological perspectives, and perhaps many others, but I also believe this study is a piece within a continuum; it will guide future investigators to consider those unaddressed perspectives of science.

6.4 Future Recommendations

In the theoretical framework of the present study, I reviewed the philosophical and the sociological perspectives of science. Even though I argued that historical and anthropological perspectives of science are also important to consider, I did not review the literature regarding these perspectives. In future studies, researchers should address the historical and the anthropological perspectives of science, and perhaps use similar strategies to teach about the NOS. I believe that anthropological perspectives of science will be the next popular subject to investigate; the cultural, political, economical, feminist perspectives of science will also be important.

In this study, I utilized semi-structured interview protocols that were manipulated after their pilot administrations. Even though, I asked emerging questions and did not strictly follow the structured interview protocol, questions I posed to participants were not completely unstructured. There may be additional issues, understanding, experiences, concerns, etc. students might have, but did not express, because they were not asked. During my conversations with the participants, I sometimes felt that I had additional questions to ask, but I did not pose them considering that those questions were beyond the Office for Regulatory Compliance approved interview protocol items, and so might have been unethical to ask. Specifically, issues concerning religious beliefs and ontological and epistemological assumptions were not explicitly addressed in the conversations. For instance, during an interview with Jacob, when he was talking about the differences of theology and religion, he said:

> Science as opposed to theology, or a lot of other fields is based on observation, as opposed to faith, or something like that. Ideas aren’t pulled out randomly. They are based on inferences you make about what you observe, or what you try to test or experiment. The role of theories and testing is very important in the field of science, whereas in theology, you can’t really test. A lot of ideas can’t test how the world - I don’t know, I don’t want to get in theology, but you know what I mean. Those are the main differences, I think.

I wanted to ask Jacob if he believes in God, or the existence of God, and in which ways and to what extent he can prove what he believes in. I did not ask those questions out of concern that they were not in the range of my approved interview protocol items. In future studies, more comprehensive and open-ended interview questions can be posed to illuminate participants' ontological and epistemological positions. Whether students believe in objective reality or not, and to what extent their beliefs have a connection with their belief about the existence of scientific facts would be an interesting research question. Whether students believe in religion or the existence of God, and in what ways these beliefs influence their understanding of the NOS are intriguing research questions, though a thorough Office for Regulatory Compliance examination is needed before any data are collected.

The value of qualitative studies lies not in the number of participants, but in the depth of the analysis. Future researchers should be less concerned about large studies and instead focus on selecting science education students in other grades so as to make comparisons with this study.

6.5 Implications

Six implications can be drawn from this investigation. First teaching about the sociological NOS is important to achieving the goal of science for all. Even though teaching about the basic tenets of the NOS have been investigated in the literature, sociological NOS was rarely addressed. The theoretical framework represented in this study calls upon science education researchers to consider the sociological characteristics of science as one of the basic tenets of the NOS. It advocates that the sociological perspectives of science should also be addressed in addition to the philosophical perspectives of science, and be represented in the portrayal of the NOS.

Second, this study calls upon science educators to give particular attention to some other important elements of science. Perhaps because scientific knowledge taught in school is persuasive and pedagogical (Kuhn, 1982), we unintentially represent an individualistic perspective of science (Ziman, 1983). Beyond that, the institutionalism, the particularism, the originality, and the collectivization characteristics of science are almost always excluded from the current NOS education research context (Carrol, 1990; Longino, 1990; Spainer, 1995; Travis & Collins, 1991). An emphasis on only subjective, empirical, tentative, value-laden, theory-laden, and human endeavor characteristics of science does not provide a complete understanding of science as it is practiced. The NOS education is not concerned with how cognitive particularism influences reviewers' decisions, or with how innovative ideas are determined to be unoriginal because these do not coincide with the norms of the current scientific paradigm. This study attempted to bring some of the aforementioned elements of science into light.

Third, this study presents a challenge to bridge the SSK perspective with NOS instructional strategies. I chose the five tenets of the NOS as my primary interest for two reasons. One is that some of those tenets were often addressed in science education literature. These tenets are the empirical, tentative, subjective, value-laden, and human endeavor characteristics of science. The fifth selected tenet; the sociological NOS is particularly important, because it has the ability to bridge the SSK perspective with science education practice. Science education literature does not have adequate information on how to bridge SSK with science education in general and NOS instructional strategies in particular. Hence, this study and its findings are of particular importance for such a bridge.

Fourth, an implicit NOS instructional strategy can improve students' understanding of the NOS. If the context of teaching is shaped differently from students' conventional science education classroom experiences, they do realize the differences and reflect upon their experiences. Students' viewpoints about science can change because of their experiences. In other words, students do not necessarily need to be taught (explicitly) to conceptualize the NOS issues.

Fifth, an authentic learning environment has a prerequisite. This study states a prerequisite for an authentic science learning experience as the open endedness of the scientific investigation. Just as Freire (1993) advocates the essence of conscientiousness and empowerment in ability to know, in an authentic scientific learning environement, students should have the ability to know; play active roles in their knowing experiences. Hence, providing oppurtunities for students to conduct open ended scientific investigation is a prerequisite. Unless students realize that they have the power of knowing through their actions, they will always be alineated from the learning environment, and they will only be taught. In this study, students conducted experiments to find scientific results that were known by neither the teacher nor the textbooks. The open endedness of the activities helped students to become the actors in their learning environment.

Sixth, this study suggests that students' understanding of the NOS is not problematic, and does not need to be corrected. I celebrate diverse perspectives regardless of how inconsistent they are with my perspectives. I do not pretent that I have all the right answers. This is why I also criticize those who believe there is one way to know and therefore to teach.

6.6 Implications for Professional Development

Becoming an effective science teacher is envisioned as a continuous process beginning from undergraduate preservice experiences to the end of a professional career (NSES, 1996). Normatively, professional development for teachers is an ongoing collaboration of pre-service and practicing teachers, university faculty, and policy makers. National science education standards maintain that, “The current reform effort requires a substantive change in how science is taught; an equally substantive change is needed in professional development practices” (NSES, 1996, Chapter 4). To achieve scientific literacy for *all,* it is important for science educators in universities to collaborate with teachers to thoroughly understand student learning in K-12 and to benefit both parties. Therefore, knowledge and ideas generated in universities need to be shared with teachers in schools, not only to enhance student outcome but also to better understand the teaching and learning that occurs in schools. Generating an instructional strategy without analyzing its practical implications in schools is a relatively pointless exercise. Therefore, it is important for practicing teachers and university faculty to collaborate in implementing and testing any innovative teaching strategy.

This study advocates teaching the sociological NOS and looks at the role of authentic scientific investigations in accomplishing this goal. Professional development experts should begin by convening to teachers that open-ended scientific investigation experiences are essential to teaching the tenets of NOS. University faculty or professional development experts can help K-12 teachers see the reasons for implementing authentic scientific investigations. Teachers may reluctant to implement open-ended investigations because of the pressure they feel with regard to student performance or standardized tests. If the exam questions focus on closed-ended scientific content knowledge, then the teachers may feel they cannot spend class time on authentic scientific investigations. Conveying to science teachers that authentic scientific investigations are important should be an objective of professional development experts, and mechanisms need to be developed to enable such investigations to “count.”

Teachers should be helped to realize that for many of their students, the only opportunity to appreciate the characteristics of formal science will be in their K-12 years. Hence, in addition to becoming familiar with tools and techniques, students need to experience the social interaction, commitment, and uncertainty of scientific investigation (Edelson, 1998). This is essential if students are to comprehend the sociological characteristics of science and develop more through NOS understandings.

Another challenge that teachers may encounter is that of locating the materials and strategies to implement authentic scientific investigations. Teachers may not have enough time and resources to design activities that truly engage students in authentic scientific investigations. K-12 school textbooks and teaching materials rarely focus on open-ended scientific investigations. University faculty can deliver designed materials and strategies to teachers who want to implement authentic scientific investigations with their students. The College Peer Review project is only one means of doing so.

University faculty can design similar projects and provide more materials for teachers. The toxicology experiment can be easily integrated in K-12 school science (Trautmann et al., 2001). Other teaching materials could be designed in other scientific field of studies, and these materials could be provided to teachers through professional development activities. University faculty can also help teachers to use these materials in their classes by providing them with technical support and organizational resources. For example, comprehensive web portals could be developed and teachers in different schools from various locations could ask their students to use these web portals to communicate with other students in other schools. The required social interaction to generate scientific knowledge could be established through the K-12 teachers and university faculty collaborative efforts.

6.7 Challenges to K-12 Education

In this study, I concluded that the CPR project positively influenced students' understandings of the sociological NOS. I also maintained the merit of authentic scientific investigations in helping students develop sociological NOS understandings. If we want students to appreciate the sociological perspectives of science, then we might ask "Should we simply teach all school science through authentic scientific investigations?"

My response to this question would be, "Yes, as much as we can," we should implement authentic scientific investigations in school science curricula. However, I do recognize the challenge of creating the conditions needed to successfully accomplish an authentic scientific investigation.

As Edelson (1998) argued, a successful adaptation of formal science involves three components: (a) tools and techniques, (b) attitudes, and (c) social interaction. The tools and techniques include the methods and knowledge of science that can be found in scientific texts. If students do not have adequate familiarity with the scientific texts or if they do not know how to effectively search for and utilize the information they need, they may not be able to complete most of the crucial tasks of their scientific investigations. Just as scientists refer to scientific texts, students need to rely on scientific texts as needed. Nevertheless, students need to realize that texts do not contain all the knowledge and methods required for a particular investigation.

Science educators agree that the school science curriculum is comprehensive (Blades, 1999). It is unrealistic to expect students to learn all the material found in texts before they conduct authentic scientific investigation. This is also the case for formal science. A scientist working in one scientific field can know about the particulars of her field but not of other scientific fields. Fortunately, this does not stop her from conducting authentic scientific investigations. Whenever it is necessary, the scientist can refer to scientific texts and utilize relevant scientific knowledge and methods to accomplish her investigation.

A similar strategy can also be adapted to school science as much as possible. Students at every level (K-12 to higher education) can begin by asking questions that are relevant to themselves and initiate their scientific investigations based on those questions. Whenever it is necessary, they can go back to the scientific texts --as scientists do-- and acquire prerequisite methods and knowledge. In lower grades, students can spend more time acquiring scientific methods and knowledge in texts. But it is still important to provide them with some opportunities for conducting authentic scientific investigations. The teacher may design the content of these investigations, and decide how much time to devote to them.

Ensuring that students in all grades are conducting authentic scientific investigations is not difficult, at least conceptually. However, problems may arise when teachers, particularly in K-12 levels, ask students to evaluate one another's performance as part of peer reviewing. Teachers may not be willing to use student generated grades in summative assessments because they question the validity of the scores students assign to each other. A common concern that was also reported by this study's participants is that students in lower grades are not qualified to grade each other, and even if they were, they would not be honest in grading their friends. Evaluating one another's work may not be formally implemented -- considered as grades -- in lower grades.

Even if we overcame teachers' and students' unwillingness to let students grade each other, the structured and institutionalized school system would be an issue. Because students' performance is evaluated subjectively in peer review, assessment experts and policy makers may reject utilizing peer evaluations as a means of evaluating student performance and ranking their achievement. Because of these concerns, high-stakes standardized exams are likely to discourage implementing authentic scientific investigations in schools, at least given current assessment methods and strategies. This presents an obstacle to the future implementation of authentic scientific investigations particularly, in K-12 levels.

In contrast, national science education standards (NCR, 1996) and science education reform documents (e.g., AAAS, 1986, 1993, 1997 2001) reflect a common interest in promoting students' understanding of the NOS. There do exist instructional strategies for conveying NOS issues to students. For example, as discussed in Section 2.13, there are explicit versus implicit and contextualized versus decontextualized NOS instructional strategies. The theoretical framework of this study advocates a sociological perspective of science in teaching the NOS. The study findings indicated that an implicit and contextualized NOS teaching strategy augmented with an authentic scientific investigation was effective in conveying the sociological NOS to students. If conveying to students the sociological NOS is an objective of science education, then this study suggests implementing authentic scientific investigations regardless even if they do not meet expectations concerning objective assessment and evaluation. Perhaps a thorough acceptance of teaching about the NOS will require radical changes in traditional assessment and evaluation methods and also a new conceptualization of student performance in science.

Kuhn (1962) stated that school science is persuasive and pedagogical. The way that science is taught in schools leads students to perceive science as merely a body of knowledge that can be found in texts. Traditional laboratory studies also promote this perspective through inauthentic scientific investigations. School science exams and standardized national tests legitimize that perspective further by emphasizing that students know about the end-products of scientific practice: knowledge and methods that can be found in written scientific texts. In that regard, science education within the institutionalized school system has become pedagogical; its aim is only to teach already existing “scientific knowledge.”

The institutionalized school system is likely to resist integrating authentic scientific investigations into school science, especially in early childhood education. If teachers do not know the definitive results --a requirement for authenticity-- then how can they objectively grade students’ performances? While acknowledging the legitimate role of fair assessment in schooling, I would argue that we should not insist on a standard for education that even organized science cannot achieve. To do so would limit the program of science education to the exploration of the already known. As for the subjectivity and imperfection of peer judgments, these are dimensions of the nature of science that we can and should acknowledge. Pretending that subjective judgment has no place in organized science is to promote a myth that chases many talented students from its further study.

6.8 Sociological Nature of Science and Students’ Interests in Science

Hodson (1998) maintained that one reason many students are not interested in learning science and/or do not choose science related career is that they perceive science as too academic and detached from their daily lives. He pointed out that school science, regardless of the effort undertaken, still discriminates on the basis of sex, ethnicity, and social class. Hodson recommends that one way to break the culture of students’ disinterest in science is to make science more accessible to them. This can be done by stressing the implications of science and making connections between experiences and underlying conceptual and procedural knowledge.

This study calls upon science educators to consider the sociological NOS as a basic tenet of science. A sociological NOS understanding will not necessarily attract more student interest. However, students may be drawn to scientific disciplines if they realize that science involves not merely acquiring knowledge and methods found in texts, but also collaboration and mutual engagement. If science is always portrayed as a static body of knowledge and students' participatory actions are disregarded, then the students who are unsuccessful comprehending that body of knowledge and who have negative attitudes toward science might never find meaningful connections to science and might never be able to develop positive attitudes. They may think that science has nothing to do with their realities, so it is not their concern. However, if students realize that their involvement and active participation play a role in generating that knowledge, they may begin to develop positive attitudes and be willing to establish connections with their daily lives. Students may find relevance with their value systems and scientific practice, because they will have the ability to shape scientific knowledge based on their interests. This may eventually increase student interest in science and science related fields, particularly among underrepresented group of students.

Being informed about the sociological NOS may empower students to be active agents of decision making in science. When students view scientific knowledge as socially constructed, shaped by human values, and legitimized through mutual engagement, they may realize that any part of this knowledge that contradicts their realities can be reexamined and eventually regenerated. Science will no longer be an alienating practice for students; instead it becomes a playground for them to participate in, where they feel welcomed.

6.9 Conclusion

Approaches to teaching the NOS should be reconsidered. In light of scientific literacy, the very objective of teaching about the NOS is to inform students about the advantages and disadvantages of science and technology to society. The advantages and disadvantages of science and its enterprise are so tentative and dynamic in their nature that one cannot decide the best way of conceptualizing the NOS.

Obviously, there are many features of the NOS that may be considered as the most important to emphasize (Atkins, 1997a, 1997b; Brickhouse, 1998; Matthew, 1998; Turner & Sullenger, 1999). This means that, there is no one NOS ideology that we should teach.

If there is no one definite perspective for the NOS science, what are we going to teach? Can we teach students that science is tentative, subject to change, empirical, theory-laden, and a human endeavor, etc. and stop worrying about the NOS instruction?

The main objective of science education students is to master scientific knowledge that is being taught to them by their science teachers, textbooks, lab manuals, computer software, or a museum consultant. Sometimes students learn scientific knowledge through inquiry, in groups, in light of their interests. What students learn is considered valuable only if it is confirmed by their teachers, textbooks, lab manuals, computer software, or a museum consultant. The assessment of the instruction measures the validity of the knowledge students' gain. The validity of this knowledge can only make sense if it is measured with respect to a reference: agreed upon by the current scientific enterprise.

Efforts to standardize science education curricula unintentionally promote the belief that students should master scientific knowledge the way it is represented to them. Similar attempts to define and teach the NOS are disingenuous. If we conceptualize teaching the NOS as promoting scientific literacy as defined by the science education reform movements, we may miss our real objective and student learning may become compartmentalized and static.

However, the NOS is not static. It is dynamic and evolving (Suchting, 1995). Rather than representing multiple paradigms of science (teaching history of science) or simplifying the NOS tenets (which may lead to it becoming static and compartmentalized), I propose that we allow science students to understand the NOS in a variety of contexts.

Teaching the NOS issues explicit has potential risks. Any attempt to teach a particular understanding reduces students' possible critical thinking skills regarding that tenet. In the short term, teaching a particular understanding of the NOS may appear efficient and convenient. However, in the long term, it is dangerous and undesirable. It simply undermines students' potential critical thinking skills and possible multiple worldviews. This type of teaching disregards students' abilities for exploration and analysis of the interrelationships among science, technology, and society. Indeed, any kind of science teaching activity that is authentic (scientific activities similar to what scientists actually do) rather than merely ideological will create the multiple perspectives that are necessary for critically reflecting upon science and its enterprise.

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Appendix A

The On-line Philosophy of Science Questionnaire

1. In your own words, what is science?

2. Science clearly differs from other disciplines like art, religion, and philosophy. What do you see as some of the most important features that distinguish science from other ways of understanding the world?

3. Now let's consider science learning, and a particular scientific phenomenon: the expansion of gases when they are heated. What percent of local middle school students would you predict actually know that gases expand when heated? How do you think most learned this fact? What do you think most imagine a gas to be, and--were you to interview them carefully--how would they describe, at a molecular level, what happens to a gas as it is warmed?

4. Now consider another phenomenon: the solubility of gases in water. What percent of local 10th graders would you predict know that gases are less soluble in warm water than in cold water? What experiences in life may have contributed to a student's misunderstanding about this concept? Why is understanding this concept important in the subject you plan to teach? What do you think students would need to do in your classroom to improve their understanding of this concept?

5. Most science teachers have students work in groups some of the time. Given the view of science you described in Questions 1 and 2, is group work more important in science class than in, say, art or English? Why or why not? Describe some types of group work

that you think are much more common in science than in science classrooms. Is this difference a problem, in your opinion? Why or why not?

6. One might argue that science achieves objectivity by using processes that minimize the importance of scientists' values, beliefs, and commitments. A laboratory report written in the third person typically doesn't even mention the scientist: the narrative centers on the objects of investigation because a scientific experiment--properly done--does not depend on the subject (that is, the investigator). What do you think of this view? And, whether you agree with it or not, critique it from an educational perspective.

Appendix B

Pilot Study Interview Protocols

1- Semi-structure Nature of Science Interview Protocol (pre and post-interviews)
Research Question: What are students' understandings of the empirical, tentative, subjective, value-laden, and sociological nature of science?

Question Bank

- In your opinion, what is science?
- What makes science different from other disciplines of inquiry, such as religion or philosophy?
- What is a scientific problem? Can you give an example?
- What are some differences between a scientific problem and another kind of problem, such as a (NAME TWO: social, philosophical, historical, cultural, psychological, theological, economical, or political) problem?
- How do scientists decide that there is a problem they should solve?*
- How can scientists be sure about their proposed solutions to those problems? (Predetermined coding for the responses of this question includes: "through experimenting" and "through peer review".)
- What is a scientific experiment?*
- Does the development of scientific knowledge require experiments? (Follow-up: Please explain your response. Can you give an example?)
- Is science objective?
- Do think you are a scientist? Why (or why not)?*
- Would you want to be a scientist?*
- Do you think that science teachers should think like scientists?*
- What is a scientific fact?
- Is there a difference between a scientific fact and other kinds of facts?
- Do scientific facts ever change? Can you give me an example?
- Do you think high school science can be organized so that students routinely discover new scientific facts?*
- How do scientists determine whether other scientists' factual claims are true?
- Is science value free?
- Are scientists influenced by societal, cultural, and personal beliefs and ways of viewing the world? Could you explain your response? Could you include any examples to justify your position?

(*) These questions were only used in pre-interviews and excluded in the post-interviews of the pilot study.

2- Semi-structure College Peer Review Interview Protocol (Post Interview only)

Research Question: What are the students' experiences with the activities of the College Peer Review Project?

Question Bank (Almost all students were asked each question)

- What did you like most about the toxicology project? What didn't you like? Why?
- Compared to other science classroom experiences you have had, how was the toxicology project unique?
- Would you like to use a peer review system with your students when you begin teaching? Why/ Why not? How?
- Did you agree with your peers' evaluations of your work? Why/why not?
- As a student, did you feel uncomfortable with any aspect of the peer review system? Did you learn something from others work in peer review system? Can you give an example?
- Did you learn something new from others' evaluations of your own work? Could you explain?
- If you compare your on-line published reports before and after the peer reviews, do you think that you improved the quality of your report? How?
- If your on-line published reports hadn't been reviewed by someone else, but you had been asked to revise them later in the semester without that feedback, do you think that you would have made the revisions you did, anyway?

Appendix C

Research Study Interview Protocols

1- Semi-structure Nature of Science Interview Protocol (Pre and Post Interviews)
Research Question: What are students' understandings of the empirical, tentative, subjective, value-laden, and sociological nature of science?

Question Bank

- In your opinion, what is science?
- What makes science different from other disciplines of inquiry, such as religion or philosophy?
- What is a scientific problem? Can you give an example?
- What are some differences between a scientific problem and another kind of problem, such as a (NAME TWO: social, philosophical, historical, cultural, psychological, theological, economical, or political) problem?
- How can scientists be sure about their proposed solutions to those problems? (Predetermined coding for the responses of this question includes: "through experimenting" and "through peer review".)
- Is science objective? (In what respect is science objective?*)
- What is a scientific fact?
- If humans did not exist in the world, would scientific facts still exist? Could you explain your response?*
- Is there a difference between a scientific fact and other kinds of facts?
- If humans did not exist in the world, would other kinds of facts still exist? Could you explain your response?*
- Do scientific facts ever change? Can you give me an example? (In what ways do scientific facts change?*)
- How do scientists determine whether other scientists’ factual claims are true?
- Is science value free?
- Are scientists influenced by societal, cultural, and personal beliefs and ways of viewing the world? Could you explain your response? Could you include any examples to justify your position?
- In your perspective is science a social activity? (How? or Why not?)*

(*) These questions are added after the revisions of the pilot study.

2- Semi-structure College Peer Review Interview Protocol (Post Interview only)
Research Question: What are the students’ experiences with the activities if the College Peer Review Project?

Question Bank

- What did you like most about the toxicology project? What didn't you like? Why?
- Compared to other science classroom experiences you have had, how was the toxicology project unique?
- Would you like to use a peer review system with your students when you begin teaching? Why/ Why not? How?
- Did you agree with your peers' evaluations of your work? Why/why not?
- As a student, did you feel uncomfortable with any aspect of the peer review system? Did you learn something from others work in peer review system? Can you give an example?
- Did you learn something new from others' evaluations of your own work? Could you explain?
- If you compare your on-line published reports before and after the peer reviews, do you think that you improved the quality of your report? How?
- If your on-line published reports hadn't been reviewed by someone else, but you had been asked to revise them later in the semester without that feedback, do you think that you would have made the revisions you did, anyway?

Appendix D

Web-Based Form Used for Student Peer Review

(The following content comprises the web-based form used by students to complete peer reviews).

Did the author address each question fully and provide good support for his or her conclusions?

- o Excellent. Exceptionally well done.
- o Good. Very well done.
- o Satisfactory. Acceptable response to all questions.
- o Poor. Minimal attention to the questions and/or serious technical problems with one or more responses.
- o Failure. Unacceptable responses; report should be restarted from scratch.

Please rate the overall quality of the writing in this report for clarity, readability, and technical accuracy (spelling errors, run-on sentences, etc.):

- o Excellent. Exceptionally well done.
- o Good. Very well done.
- o Satisfactory. Acceptable response to all questions.
- o Poor. Minimal attention to the questions and/or serious technical problems with one or more responses. May be salvageable with extensive rewriting.
- o Failure. Unacceptable responses; report should be restarted from scratch.

What was a particular strength in this experimental design?

(Scrolling text box)

Do you agree with the conclusions?

Do they appear to be supported by the results of the experiment?

(Scrolling text box)

What suggestions can you make for improving the experimental design?

(Scrolling text box)

Appendix E

Student Demographics Questionnaire

Directions: The following information is confidential and access to it will be restricted to researchers. If you prefer to not answer a question, simply leave it blank. When you are finished, click the "Submit" button at the bottom of the screen.

- Are you in a teacher education program (yes/no)?
- Are you currently an (undergraduate/graduate student)?
- What is your current major field of study? (*text box*)
- If you have a dual major, what is your second major field of study? (*text box*)
- When do you plan to complete your current degree? (2001, 2002, 2003, 2004, 2005, later)
- What is your gender? (male/female)
- Do you identify yourself as a member of one or more of the following minority groups: African-American, Hispanic, Native American? (yes/no)
- Have you ever done scientific research in a setting other than a conventional college class? (yes/no)
- If you answered "yes" to the preceding question, please describe the research, the setting, and the length of time you were involved (*scrolling text box*)

(Submit button)

Appendix F

Final Student Questionnaire & Study Participants' Responses

(The following items were posed to students after they completed the CPR project. The questionnaire format was different from what students see on the monitors, such that all items included 5-point Likert scales using radio buttons. These scales ranged from Strongly Agree to Strongly Disagree. Participants responses are shown in Table F.1).

1- I learned something by writing peer review comments.

2- I felt qualified to give meaningful peer review comments about other students' reports.

3- I believe that the peer reviews I wrote should be helpful to the students that received them.

4- Peer reviewing other students has helped me to think more critically.

5- Peer reviewing other students has helped me to improve my own scientific writing.

6- I received useful peer review comments about my own report.

7- The quantitative scores I received from peer reviewers were fair.

8- I changed my mind about something in my report because of comments I received through peer review.

9- It is easier to say what I really think when I don't have to sign my name or meet in person with the students who wrote the research reports.

10- I think that meaningful peer review is a reasonable expectation for high school students.

11- I think that meaningful peer review would be a reasonable expectation for college students.

12- If I taught science, I would like to use some type of formal student peer review.

Table **F.1**: Study Participants' Responses to the Final Student Questionnaire.

#	Item*	Frank	Cindy	Jacob	Liz	Megan
1	I learned something by writing peer review comments.	3	4	4	4	4
2	I felt qualified to give meaningful peer review comments about other students' reports.	4	4	5	5	5
3	I believe that the peer reviews I wrote should be helpful to the students that received them.	4	3	5	4	5
4	Peer reviewing other students has helped me to think more critically.	4	4	4	5	5
5	Peer reviewing other students has helped me to improve my own scientific writing.	4	5	4	3	5
6	I received useful peer review comments about my own report.	1	4	4	5	5
7	The quantitative scores I received from peer reviewers were fair.	3	4	3	4	3
8	I changed my mind about something in my report because of comments I received through peer review.	4	5	2	3	4
9	It is easier to say what I really think when I don't have to sign my name or meet in person with the students who wrote the research reports.	3	4	2	5	4
10	I think that meaningful peer review is a reasonable expectation for college students.	4	5	5	5	4
11	I think that meaningful peer review would be a reasonable expectation for high school students.	4	5	4	4	3
12	If I taught science, I would like to use some type of formal student peer review.	4	5	4	4	3

* 1= Strongly Disagree, 2=Disagree, 3=Neutral, 4=Agree, 5= Strongly Agree.

Appendix G

CPR Project Wise Participation in Fall 2001

(Fall 2001, CPR project wise participation during the pilot study phase; institution, target course, and the approximate number of student participants).

University	Target Course	Students
University of New Hampshire	Science Methods	25
Hofstra University	Science and Technology in the Curriculum	50
Penn State University	Teaching Secondary Science I	25
Auburn University	Research in Science Education	20
Columbus State University	Introduction to Life in Space	20
West Texas A & M University	Natural Sciences I & II	60
Texas A&M University Galveston	Succeeding in Science	180
University of Northern Colorado	Foundations of Biological Research	15
California State University	Science Methods II	20
Black Hills State University	Integrated Science for Teachers	44
Michigan State University	Reflection and Inquiry in Teaching Practice	20
Western Michigan University	Life Science for Elementary Instructors	100
University of Houston Downtown	Physical Science Studies	60
University of South Florida	Science/Technology/Society Interaction	25
Xavier University of Louisiana	General Chemistry Lab II	65
Southwest Texas State University	Nature Study	10

Appendix H

CPR Project Wise Participation in Fall 2002

(Fall 2002, CPR project wise participation during the research study phase; institution, target course, and the number of student participants).

University	Target Course	Students
Penn State University	Teaching Secondary Science I	21
Auburn University	Research in Science Education	11
West Texas A & M University	Natural Sciences I & II	57
Southwest Texas State University	Nature Study	10

Appendix I

Student On-line Consent Form

(The following is the text of a student consent form that was administered on-line. Its format was altered for readability on a computer screen)

Title of project: Environmental Inquiry by College Science Students: Original Research and Peer Review Using Web-Based Collaboration Tools

Person in charge: Prof. William S. Carlsen, College of Education, 173A Chambers Building, Penn State University, University Park, PA 16803

1. This section provides an <u>explanation of the study in which you will be participating</u>:

The study in which you will be participating is intended to evaluate the use of peer review by college students in science teaching and learning. It complements a science experiment that you will be doing in one of your classes (a bioassay using lettuce seeds).

If you agree to take part in this study, we will ask you to complete a brief on-line questionnaire about your status as a student, such as your year of study and whether you are in a teacher education program. You will also be asked to complete a brief questionnaire at the end of the project about your experience doing the bioassay and peer review. The researchers will have access to the bioassay report and peer reviews that you submit. However, identification codes will be used in our analysis; all of your work will be anonymous unless you choose to “publish” your final report on our website with your name (a decision that you may make at the end of the project). If you agree to complete the questionnaire, you may later change your mind or choose not to answer specific questions.

Your participation in this research will take 10-15 minutes of your time, above and beyond the work required for your class science project (which includes an experiment and peer review using our website).

By participating in this research project, we believe that you may get a better understanding of the nature of science. We are aware of no other obvious benefits or risks of participating.

If you do not wish to be involved in the research project, you may still complete the science experiment and use our on-line tools. We will ask only for information necessary to create a user account so you can use our peer review system. We will not ask you to complete the questionnaires.

Your report, the peer reviews that you write, and peer reviews of your work (completed by other students) are part of your regular coursework: your instructor will have access to those materials and may consider them as part of your grade. Your instructor will explain how he or she plans to use those materials.

2. This section describes <u>your rights as a research participant</u>:

You may ask any questions about the research procedures and expect a prompt answer. Questions can be addressed to the project director, Prof. William Carlsen or to your instructor. Prof. Carlsen can be reached via email (wcarlsen@psu.edu), phone (814-865-5664), or mail (173A Chambers Building, College of Education, Penn State University, University Park, PA 16803).

We will protect the confidentiality of your work. Analysis of data will be done using identification codes, not names. We will use pseudonyms in any publications that we write. The draft bioassay report that you write will be anonymous to reviewers. You will also write two anonymous peer reviews of other students' work. The two exceptions to our general rule of anonymity were described above and are reiterated here: (1) Your instructor will have access to your work and will know that it is yours, and (2) You will have the option of "publishing" a final version of your report (with your name) at the end of the project. This step is entirely optional.

Your participation is voluntary. If you choose today to participate in the research project, you may later choose to withdraw, in which case we will not ask you to complete the final questionnaire and will delete from our records any information you provide today. Please note, however, that your instructor may still expect you to complete the bioassay project and peer review process (or an alternative) as a class assignment: please talk with him or her.

3. Please check one of the following boxes. Print a copy of the form if you wish, then press Submit:

- ❑ I agree to participate in an evaluation study of peer review in science teaching and learning. I understand the information given to me and agree to the conditions of this study as described. I will receive no compensation for participating. My participation in this research is voluntary, and I may withdraw from this study at any time by notifying Prof. Carlsen. I am 18 years of age or older.

- ❑ I do not wish to participate in the evaluation study. I will still be able to register to use the on-line tools required to complete my coursework requirements. I will not be expected to complete a questionnaire at the end of the project.

[SUBMIT BUTTON]

Note: After clicking the “Submit” button on the above form, a brief “thank you” screen will be displayed that will include instructions for obtaining a paper copy of the consent form.

Appendix J

Student Consent Form for Penn State Students

Title of project: Environmental Inquiry by College Science Students: Original Research and Peer Review Using Web-Based Collaboration Tools

Person in charge: Prof. William S. Carlsen, College of Education, 173A Chambers Building, Penn State University, University Park, PA 16803

a. This section provides an <u>explanation of the study in which you will be participating</u>:

The study in which you will be participating is intended to evaluate the use of peer review by college students in science teaching and learning. It complements a science experiment that you will be doing in SCIED 411 (a bioassay using lettuce seeds). There are two components of the study:

1. If you agree to take part in this study, we will ask you to complete a brief on-line questionnaire about your status as a student, such as your year of study. You will also be asked to complete a brief questionnaire at the end of the project about your experience doing the bioassay and peer review. We will have access to the bioassay report and peer reviews that you submit. However, identification codes will be used in our analysis; all of your work will be anonymous to others unless you choose to “publish” your final report on our website with your name (a decision that you may make at the end of the project). If you agree to complete the questionnaire, you may later change your mind or choose not to answer specific questions.

Your participation in this research will take 10-15 minutes of your time, above and beyond the work required for your class project (which includes an experiment and peer review using our website). By participating in this research project, we believe that you may get a better understanding of the nature of science. We are aware of no other obvious benefits or risks of participating.

If you do not wish to be involved in the research project, you may still complete the science experiment and use the on-line tools. We will ask only for information necessary to create a user account so you can use our peer review system. We will not ask you to complete the questionnaires.

Your report, the peer reviews that you write, and peer reviews of your work (completed by other students) are part of your regular coursework: we will have access to those materials and will consider them as part of your grade.

2. If you agree to take part in the study, we may ask to interview you about some of your views about the nature of science and your experience conducting the bioassay project. The interview will take approximately 20 minutes. If you agree to be interviewed (this is voluntary and will have no effect on your grade), the interview will be videotaped by a mounted fixed-position camera. The tape will be transcribed by the researchers using pseudonyms for you and any other individuals named in the interview. The tapes will be locked in a secure location and erased within five years. Access to the tapes will be restricted to project staff who have completed Penn State's Human Subject training program and have been authorized by Prof. Carlsen.

b. This section describes your rights as a research participant:

You may ask any questions about the research procedures and expect a prompt answer. Questions can be addressed to the project director, Prof. William Carlsen or to your instructor. Prof. Carlsen can be reached via email (wcarlsen@psu.edu), phone (814-865-5664), or mail (173A Chambers Building, College of Education, Penn State University, University Park, PA 16803). Questions concerning the rights of participants can also be directed to the Office for Research Protections (814-865-1775).

We will protect the confidentiality of your work. Analysis of data will be done using identification codes, not names. We will use pseudonyms in any publications that we write. The draft bioassay report that you write will be anonymous to reviewers. You will also write two anonymous peer reviews of other students' work. The two exceptions to our general rule of anonymity were described above and are reiterated here: (1) Your instructor will have access to your work and will know that it is yours, and (2) You will have the option of "publishing" a final version of your report (with your name) at the end of the project. This step is entirely optional.

Your participation is voluntary. If you choose to participate in the research project, you may later choose to withdraw, in which case we will not ask you to complete the final questionnaire. Please note, however, that we still expect you to complete the bioassay project and peer review process as a class assignment.

3. Please check one of the following boxes.

- ❑ I agree to participate in an evaluation study of peer review in science teaching and learning. I understand the information given to me and agree to the conditions of this study as described. I will receive no compensation for participating. My participation in this research is voluntary, and I may withdraw from this study at any time by notifying Prof. Carlsen. I am 18 years of age or older.
- ❑ I do not wish to participate in the evaluation study. I will still be able to register to use the on-line tools required to complete my coursework requirements. I will not be expected to complete a questionnaire at the end of the project or to be interviewed.

Your name (please print) ____________________________________

Your signature ____________________________________

Today's date _______________

William S. Carlsen, Principal Investigator
Professor, Science Education
173A Chambers Building

____
Signature

Penn State University
University Park, PA 16803
wcarlsen@psu.edu (814) 865-5664

Appendix K

The In Vivo Codes and the Sociologically Constructed Codes

This section is devoted to the codes I generated through my coding strategies. In this study, the propositions depicted by the visual diagrams are the final products of the coding strategies. For the details of these propositions and the visual diagrams, please refer to Chapter 5 (Findings of the Study).

In the interview analysis, I used strategies recommended by Strauss and Cobin (1990), including open coding, axial coding, and selective coding. The first time I read the verbatim transcripts, I employed open coding. I coded all of the phenomena that interviewees described (the incidents) without any particular concern for linking them to a specific category or to themselves. The second time I read the transcripts, I looked for possible connections among the codes that were generated in open coding and attempted to categorize them. Strauss and Cobin (1998) call this phase axial coding (i.e., the phase in which the researcher makes connections between the categories and the sub-categories). In the selective coding phase (close to my last readings of the transcripts), I generated structural relationships between the codes and the categories. These structured relationships helped me to delete some of the codes and merge some others under one major code or a more encompassing category. The outcomes of the selective coding were the propositions generated as research findings. Chapter 4 (Methods of Inquiry) describes in more detail the integration and the organization of these codes and the categories. It is essential to note that in the pilot study, I generated more codes through open coding than I did in the research study.

In this section, the codes that I generated and utilized are represented to better inform the reader about the analysis. These codes fall into two categories: In vivo codes and sociologically constructed codes. The in vivo codes are the actual words and phrases used by the respondents (Strauss, 1987). The sociologically constructed codes are the researcher-constructed labels that best capture a description of a phenomenon as it is highlighted in the textual data (Douglas, 2003). Table K.1 lists the in vivo codes and Table K.2 lists the sociologically constructed codes that I generated in analyzing participants' NOS understandings. In both tables, the second column represents the main categories encompassing the codes.

Table **K.1:** The in Vivo Codes and the Main Categories Used in the Analysis of Students' NOS Understandings.

The in vivo Codes		**Main categories they fall into**
Testing Observation Evidence Predictions Logic	Data Tangible hypothesis Experiment Proof Standards	Empirical
Peer review Human creation Perfect system Communication Social enterprise	Collaboration Social activity Group work Society	Sociological
Objective Physical Reality Good science Facts Progressive Best answer	Found in Nature Universal Study of nature Repeated again and again Physical phenomenon Testing again and again	Objective – absolute truth
Non-scientific fields Non-stable	So much out there Everything around us	Subjective
Ongoing process Subjective	Falsiability	Tentative
Human nature People's ideas	Human practice	Human endeavor
Beliefs change Moral values	Subjective creators Depends on people	Value-laden

Table **K.2:** The Sociologically Constructed Codes and the Main Categories Used in the Analysis of Students' NOS Understandings.

The Sociologically constructed codes	**Main categories they fall into**
Empirical Scientific facts, knowledge, and claims	Empirical
Based on location Based on culture	Subjective
Absolute truth Objective reality	Objective
Sociological Collectivization Legitimizing scientific knowledge	Sociological
Subject to change Scientific knowledge changes	Tentative
Personal interest Scientist's background Particular culture Planning and design stages	Value-laden
Human activity Human imagination Human creativity	Human endeavor

In analyzing students' experiences, I used the same strategies (open, axial, and selective coding) that I utilized for my analysis of NOS understandings. Identifying, categorizing, and grouping the codes for students' experiences was easier than doing this same analysis from students' NOS understanding. Table K.3 represents the experience codes, which were mostly in vivo codes, except for "eponymous feedback" (meaning "not anonymous)".

Table **K.3:** The Codes and the Categories Used in the Analysis of Students' Experiences.

Codes (Mostly the in vivo, except *)	**Categories they fall into**
Original research Group work Peer review	Liked in the project
Lack of constructive feedback Incomplete feedback Quantitative scoring in peer review Late reviews Nothing	Didn't like in the project
Original aspect On-line peer review Peer review	Found unique in the project
Willing to use as it is Unwilling to allow students grading Unqualified Not mature Emotional	Intend to use similar peer review system
Learned new things Did not learn new things	Learned new things?
Made changes based on the reviews	Made changes?
Agree with reviewers Disagree with reviewers	Agreed with comments?
Improved after the review Did not improve after the review Feedback merely on grammar and spelling	Improved after the review?
Eponymous feedback* Second time experimenting Only qualitative feedback	Suggestions

* This code was a sociologically constructed code.

VITA

Bugrahan Yalvac

The author graduated from the Middle East Technical University (METU) in Ankara, in 1996, with Bachelor of Science degrees in Physics Education and Physics. He worked as a teaching assistant in the Science Education department at METU for 3 years. In 1998, he obtained a Master of Science degree in Science Education (with an emphasis on Physics Education) from METU. His master thesis is entitled "Effect of instruction on students' understanding of electric current concept using Conceptual Change Texts at 6th grade." He moved to State College, PA to pursue a Philosophy of Doctorate degree in Science Education at Pennsylvania State University in 1999. During his PhD studies, he worked at the Science Education Program, Curriculum and Instruction department, at Pennsylvania State University as a research and a teaching assistant. He also assisted in teaching a Science, Technology, and Society (STS) course offered at the same university. Because of his interest in STS issues, he minored in STS.

The author has been working as a research fellow at the VaNTH Engineering Research Center (ERC) at Northwestern University since 2003. VaNTH is a collaboration of Vanderbilt University, Northwestern University, University of Texas in Austin, and Health and Science Division of Harvard and Massachusetts Institute of Technology, aimed to improve biomedical engineering curricula in K-12 and higher education. In the center, his primary responsibility is to provide guidance to engineering faculty in developing and evaluating the instructional materials and teaching strategies derived from the sound learning theories and teaching methods.

Retrospectively, the author's academic interests include; students' conceptual understandings, test construction, assessment and evaluation, Science, Technology, and Society issues, philosophy and sociology of science, qualitative and quantitative research methods, ethics and values in science and engineering, and finally engineering design and communication.