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GRADE SIX STUDENTS' UNDERSTANDING OF THE NATURE OF SCIENCE

by

Donald Brian Cochrane

Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy

at

Dalhousie University
Halifax, Nova Scotia
July 2000

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by Brian Cochrane

in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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Donald Brian Cochrane

DEDICATION

To my parents, Marion and Lester, for their continued support and encouragement, to my children, Jennifer, Sean and Christine for their patience and understanding, and to my wife Dianne for her love and her faith that some day this thesis would be completed.

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ABSTRACT

The goal of scientific literacy requires that students develop an understanding of the nature of science to assist them in the reasoned acquisition of science concepts and in their future role as citizens in a participatory democracy.

The purpose of this study was to investigate and describe the range of positions that grade six students hold with respect to the nature of science and to investigate whether gender or prior science education was related to students' views of the nature of science. Two grade six classes participated in this study. One class was from a school involved in a long-term elementary science curriculum project. The science curriculum at this school involved constructivist epistemology and pedagogy and a realist ontology. The curriculum stressed hands-on, open-ended activities and the development of science process skills. Students were frequently involved in creating and testing explanations for physical phenomena. The second class was from a matched school that had a traditional science program.

Results of the study indicated that students hold a wider range of views of the nature of science than previously documented. Student positions ranged from having almost no understanding of the nature of science to those expressing positions regarding the nature of science that were more developed than previous studies had documented. Despite the range of views documented, all subjects held realist views of scientific knowledge. Contrary to the literature, some students were able to evaluate a scientific theory in light of empirical evidence that they had generated.

Results also indicated that students from the project school displayed more advanced views of the nature of science than their matched peers. However, not all students benefited equally from their experiences. No gender differences were found with respect to students' understanding of the nature of science.

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CHAPTER 1

RATIONALE

Introduction

The term *scientific literacy* is often used to describe a group of related outcomes that form the core of current educational reform in science education. The Council of Ministers of Education, Canada (CMEC, 1997) defines scientific literacy as "an evolving combination of the science-related attitudes, skills, and knowledge students need to develop inquiry, problem-solving, and decision-making abilities, to become lifelong learners, and to maintain a sense of wonder about the world around them" (p. 4).

Science education that focuses on scientific literacy includes a broader range of goals and practices than found in typical science education experiences (American Association for the Advancement of Science [AAAS], 1989, 1993; Bybee, 1985; National Research Council [NRC], 1996; Pella, O'Hearn, & Gale, 1966; Roberts, 1983). In addition to the traditional goal of having academically elite students acquire science content and concepts, the goals of scientific literacy also include the development of students' understanding of the nature of science, understanding of the relationships among science, technology, society and the environment, development of science process skills, technological problem-solving skills, and decision-making skills (CMEC, 1997; Yager, 1993). Scientific literacy advocates science education for all students (AAAS, 1989; Lee, 1997), using a social and contextual approach that places science in the real world and connects it to the lives of students (AAAS, 1989, 1993; CMEC, 1997; Yager, 1993), acceptance of constructivist learning principles (AAAS, 1989, 1993; CMEC, 1997; Reeves & Ney, 1992; Staver, 1998), an emphasis on the nature of science (AAAS, 1989, 1993; Aikenhead, 1991; CMEC, 1997; Nadeau & Desautels, 1984; Reeves & Ney, 1992; Staver, 1998) an increased focus on technology (AAAS, 1989, 1993), and a reduced focus on the breadth of science content (AAAS, 1989). While the term scientific literacy has been in use for the greater part of this century (Pella et al., 1966), many of the key aspects associated with scientific literacy can be traced back even further (Hurd, 1998). Scientific literacy is often associated with the Science-Technology-Society (STS) movement (Yager, 1993), or more recently the Science-Technology-Society-Environment (STSE) movement (CMEC, 1997). STS is often referred to as a mechanism for the achievement of scientific literacy goals (Yager, 1993).

Having students develop an understanding of the nature of science is a key goal of scientific literacy (Alberta Education, 1990; AAAS, 1989, 1993; Atlantic Provinces Education Foundation [APEF], 1998; CMEC, 1997; Duschl & Gitomer, 1991; Hodson, 1999; Nadeau & Desautels, 1984; NRC, 1996; Roberts, 1983; Science Council of Canada [SCC], 1984). Different rationales exist for the inclusion of the nature of science in the school science curriculum (Driver, Leach, Millar, & Scott, 1996). The democratic argument contends that having citizens with an understanding of the nature of science is a requirement of an informed participatory democracy. The cultural argument contends that understanding science is an important aspect of understanding western culture. The moral argument contends that science represents principles that should be valued in society and therefore nurtured in students. The science learning argument contends that an understanding of the nature of science facilitates the learning of science concepts.

The most commonly cited of these rationales are the democratic argument and the science learning argument. The democratic argument relates to the student's role as a future citizen (AAAS, 1989, 1993; CMEC, 1997; Driver et al., 1996; Duschl & Gitomer, 1991; Hodson, 1999; NRC, 1996; Smith & Scharmann, 1999). Science, it is argued, has such a large impact on the world that decisions regarding science and its uses are simply too important to be left to scientists. If the only individuals in our society who have some understanding of the nature and purpose of science are scientists, we run the risk of excluding the vast majority of the population from discussions and decision-making processes involving science-related issues (AAAS, 1989, 1993; CMEC, 1997; SCC, 1984). Thus, allowing students to complete their formal education without an understanding of the nature of science compromises their ability as citizens to participate in discussions and decisions on issues that involve the application of scientific knowledge (Harlen, 1993; Hurd, 1998). Many of the issues involved in public discourse today involve the interpretation or application of science and technology (Duschl & Gitomer, 1991), and as the science and technology components of public decision making continue to expand, understanding the nature of science will increase in importance. Giere (1991) argues that in the extreme case the ability to understand and evaluate knowledge claims from science can "literally be a matter of life and death for you, your family, and if you achieve a position of power in business or government, for many others as well" (p. 4).

The science learning argument relates to the goal of having students construct and understand the key concepts and ideas that explain the physical world from a scientific perspective (AAAS, 1989, 1993; APEF, 1998; CMEC, 1997; Cavallo & Schafer, 1994;

Cleminson, 1990; Harlen, 1993). However, students often enter science classrooms with their own intuitive explanations for physical phenomena (Driver, 1989; Erickson, 1979). It is not only desirable that students construct or acquire key scientific ideas or replace their naïve ones, but that these ideas be constructed or chosen on the basis of good reasons, rather than on the basis of authority (Siegel, 1988; Strike & Posner, 1983). The Science Council of Canada (1984) states that:

> Scientists study the physical environment and develop ideas that explain how things work. Similarly, in learning to cope with the world, young children develop their own explanations for phenomena, and these ideas enable them, more or less adequately, to understand and relate to the environment. Inasmuch as this activity parallels that of the scientist, at least in purpose, it is important for students to learn that they can understand and deal with the world by means of their own observations and constructed explanations, that all such explanatory frameworks have their limitations, and that science offers frameworks for explanation and control which, while also limited in scope, have been shown to possess particular explanatory power and which have thus become accepted by the scientific community and by society as a whole (p. 17).

However, the scientists who have researched, debated, and passed judgement on the publicly accepted scientific explanations have an understanding of the nature of science that allows them to evaluate knowledge claims in particular fields and make decisions involving theory choice in those areas. If we expect that students will construct and/or adopt the same scientific explanations that scientists do, then these students must first have the requisite knowledge and skills for the task. In short, we must develop in them an understanding of the nature of science that will assist them in evaluating knowledge claims in science (Duschl & Gitomer, 1991).

The vision of scientific literacy previously described conflicts with descriptions in the literature of the goals and practices of traditional science education. The goal of science education has traditionally been to teach science content to an academic elite to ensure a supply of future scientists (Driver & Leach, 1993). This content is typically taught in a static, dogmatic manner that contradicts the open, creative nature of science (AAAS, 1989; Reeves & Ney, 1992; Yerrick, Pederson, & Arnason, 1998). According to the AAAS (1989), typical science curricula:

> emphasize the learning of answers more than the exploration of questions, memory at the expense of critical thought, bits and pieces of information instead of understanding in context, recitation over argument, reading in lieu of doing. They fail to encourage students to work together, to share ideas and information freely with each other, or to use modern instruments to extend their intellectual capabilities (p. 14).

Thus, science education is in the midst of tremendous change. This change is closely associated with the goal of scientific literacy and the methods of STS science. Within the framework of scientific literacy, understanding the nature of science is a major goal of its own, plus it is a necessary precondition for another major component of scientific literacy—the reasoned acquisition of scientific concepts.

Despite a great deal of effort, no curricular model exists that has demonstrated the achievement of scientific literacy in the general population (Hazen & Trefil, 1991). Some critics of the goals of scientific literacy have emerged. For example, Hazen and Trefil argue that the key to scientific literacy is being able to use and apply scientific information and explanations and that this does not require an understanding of the nature of science. Harding and Vining (1997) advocate an approach to science education that focuses on students' understanding of the publicly accepted scientific explanations for key phenomena. They state, "We can prepare students best for the future, not by teaching them about the methods of science, but by giving them a framework of knowledge about each subject so they have something to build on in the future" (p. 974). Shiland (1998) advocates a vision of scientific literacy that includes the ability to use, rather than construct, the commonly accepted theories of science. He contends that the current vision of scientific literacy amounts to students having to spend “much of their time trying to invent 200 years of scientific knowledge in the span of a K–12 education” (p. 616). Shiland argues that the field of science education will advance with respect to assessment results when curriculum documents indicate which specific theories are to be taught and evaluated. His notion of scientific literacy appears to promote the goals of traditional science education rather than the broader set of goals relating to scientific literacy.

Boulton and Panizzon (1998) have criticized Harding and Vining’s (1997) conclusions, and by extension, those of Hazen and Trefil (1991) and Shiland (1998). Boulton and Panizzon argue that treatment of scientific content and concepts without addressing epistemological and procedural issues is both pedagogically ineffective and educationally inappropriate. Research on students’ learning of science concepts supports Boulton and Panizzon’s contention that addressing epistemological issues improves students’ learning of science concepts (Driver et al., 1996; Posner, Strike, Hewson, & Gerzog, 1982).

Shamos (1995) contends that the achievement of scientific literacy, as commonly defined, in the general public is “a utopian dream” (p. xii). He concludes that if we are to achieve scientific literacy we must define it less in terms of content and more in terms of understanding the nature of science. He refers to this approach as “science awareness” and contends that it should be the goal for all non-science majors.

Although critics of the scientific literacy movement are in a small minority, concerns regarding the appropriateness of the goals of scientific literacy have been expressed, with a range of positions being articulated. These concerns include whether or not scientific literacy, as commonly defined, is a desirable goal, as well as whether or not it is achievable.

Despite the fact that there are no working models for the attainment of scientific literacy in the general public (Shamos, 1995), curriculum guidelines and texts are being written with the aim of achieving this vision. One of the key goals of these documents is the development of students' understanding of the nature of science. Two important preliminary tasks arise in this curriculum development process. The first task is determining what vision or view of the nature of science should be represented in the curriculum, and thus cultivated in students. The second task is determining what views of the nature of science students currently hold. At the completion of these two tasks, curriculum developers and teachers can determine what views and understandings of the nature of science students already possess, what views and understandings are desirable in students, and therefore may begin to design learning experiences to bridge this gap.

The literature indicates that no agreement is likely to be reached in the near future regarding what view of the nature of science should be represented in the curriculum. Many science educators and science curriculum researchers advocate the use of constructivist epistemology in the school system (Leach, Driver, Millar, & Scott, 1997; Roth & Roychoudhury, 1993, 1994; Ryan & Aikenhead, 1992; Staver, 1998). This constructivist stance regarding epistemology of science has been criticized by some writers for an extended period of time (Matthews, 1994, 1998), while many others have only recently entered the debate (Alters, 1997; Eflin, Glennan, & Reisch, 1999).

The development of students' understanding of the nature of science is a fundamental goal of scientific literacy. However, research outlining students' views of the nature of science is minimal at best, particularly below the high school level. Much more research is required that examines the views of the nature of science that students hold, particularly young students, and how those views have developed and are justified.

Purpose

Current science education reform, under the title "scientific literacy," describes a crucial role for students' understanding of the nature of science. This understanding serves as a key feature in students' acquisition of key science concepts, as well as in their future role as citizens capable of participating in discussions and decisions involving science-related topics and issues. While current science curriculum reform has a strong theoretical base in epistemology and learning theory, it has a scant research base in the area of students' understanding of the nature of science. For example. researchers in science education have been investigating students' misconceptions and naïve conceptions with regards to science concepts for a quarter century. However, little research has gone into investigating the sorts of epistemological stances that students hold and what effects these epistemologies have on their abilities to develop scientific literacy. Grosslight, Unger, Jay, and Smith (1991) state that:

> There is increasing recognition in the science education community that students frequently come to class not only with naïve theories about the particular subject matter that they are studying, but also with naïve epistemologies, and that students must make changes in their naïve epistemologies if they are to understand the scientists' specific theories (p. 800).

Given that students' understanding of the nature of science has not been extensively examined, there would seem to be a small research base upon which to build such a huge platform of curriculum reform. While this does not mean that the general direction of curriculum change will not be fruitful, it does mean that it is not well grounded in research about students' epistemological positions.

Based on the AAAS (1993) publication "Benchmarks for Scientific Literacy," curriculum documents are setting expectations for students' understanding of the nature of science as they progress through the school system (APEF, 1995; CMEC, 1997; NRC, 1996; National Science Teachers Association [NSTA], 1995, 1996). However, such frameworks appear to be based on assumptions about the developmental patterns of students' views of the nature of science. While research indicates that most students have a poorly developed understanding of the nature of science (Carey, Honda, Evans, Jay, & Unger, 1989; Meichtry, 1992), little attention has been paid to identifying the range of positions held by students. This is especially true for children and early adolescents.

Curriculum writers, textbook authors, and teachers are charged with developing science learning experiences that will result in students developing understandings of the nature of science that will promote the acquisition of scientific literacy. However, in order to engage in this curriculum development task, more must be known about students' views of the nature of science and why they hold those views. The purpose of this research, therefore, was to investigate grade six students' understanding of the nature of science and the nature of scientific knowledge. Grade six was chosen because: 1) it is the lowest grade level at which the Common Framework of Science Learning Outcomes (CMEC, 1997) stipulates outcomes specifically for the nature of science; 2) the end of grade six marks a transition, in many North American school systems, between elementary and secondary education. Thus, planning for secondary programs is based on the assumption that students have achieved the outcomes for the grade six level; and 3) while there is little research in the area of students' understanding of the nature of science and the nature of scientific knowledge, the vast majority of existing research has been done at the secondary level.

Research Questions

The questions that this research investigated were:

1. What range of positions do grade six students hold with respect to the nature of science and scientific knowledge?
2. Are grade six students' views of the nature of science related to gender or prior exposure to science curriculum?

Significance of the Study

The American Association for the Advancement of Science (1993), the National Research Council (1996), and the Council of Ministers of Education, Canada (1997), have all identified the development of students' understanding of the nature of science as a major goal for science education. Based on the science education frameworks developed by these organizations, a tremendous amount of time, effort, and energy are being given to the development of science curriculum guidelines and resources. It would seem beneficial to have this magnitude and direction of curricular reform justified on the basis of existing research on children's understanding of the nature of science. And yet there is very little research that has examined the range of views of the nature of science that students hold at particular phases of their educational experience and/or identified factors or experiences that contribute to those views. Since this research examines these issues, it has implications for the planning, development, and implementation of all school science programs aimed at achieving scientific literacy. By describing the range of views of the nature of science held by grade six students, it will be possible to evaluate some of the existing research and assumptions regarding students' views of the nature of science and how these views develop. By determining if prior science education affects students' understanding of the nature of science, it will be possible to examine the role of science curriculum in the development of students' understanding of the nature of science. Therefore, this research will contribute to the body of research that curriculum developers, publishers, and teachers can utilize in developing curriculum and learning experiences for the achievement of scientific literacy in students.

CHAPTER 2

REVIEW OF THE LITERATURE

While this study deals specifically with students' understanding of the nature of science, it relates to a broad range of issues in philosophy, nature of science, learning theory, and science curriculum. Within philosophy, both ontological and epistemological issues are involved.

Issues Regarding the Philosophy of Science

In the literature two contrasting ontological positions are portrayed, realism and constructivism. The central attributes of the realist position are that there exists a reality independent of human existence that can be objectively and accurately described and explained, and that these descriptions and explanations can be determined to be true or untrue absolutely (Nussbaum, 1989; Reeves & Ney, 1992; Roth & Roychoudhury, 1993; 1994; von Glasersfeld, 1995, 1996; Yager, 1991). Staver (1998) refers to this as the *correspondence* theory of truth, since it hinges on an absolute mapping, or correspondence between reality and statements that describe that reality.

Within realism, there have traditionally been two divisions—empiricism and rationalism. These subsets differ in the mechanism used to determine a scientific statement's correspondence with reality. Empiricists (notably Bacon, Locke, and Hume) argue that experimentation and subsequent observations (or measurements) allow us to determine the truth of statements. That is, observations of reality based on the senses can be used to determine correspondence between a particular statement and reality. Rationalists (notably Plato, Descartes, and Kant) contend that pure logic is the appropriate mechanism for the verification of truth (Nussbaum, 1989).

Rationalism had Euclidean geometry as a working example of logical truth. Euclid's ten axioms were considered to be "obviously or self-evidently true" (Musgrave, 1993, p. 178) and these axioms were then used to build the entire structure of Euclidean geometrical theorems through logic. Newtonian physics, the pre-eminent system for describing and explaining the physical universe at the start of the 20th century, was also based on Euclidean geometry and Cartesian time-space duality. Thus, at the start of the 20th century, there existed a working model of rationalist truth that was widely accepted.

The realist arguments for confirmation of truth had been criticized as early as the 5th century B.C., when the skeptics argued that, "it is logically impossible to establish the 'truth' of any particular piece of knowledge. The necessary comparison of the piece of knowledge with the reality it is supposed to represent cannot be made because the only rational access to that reality is through yet another act of knowing" (von Glasersfeld, 1995, p. 6). This argument is often referred to as the *root paradox* (Staver, 1998).

Despite philosophical objections based on the root paradox, realism has dominated western philosophical thought for centuries. However, in the first half of the 20th century, realist claims to absolute truth came under scrutiny. Reasons for this varied. With the advent of non-Euclidean geometry, other mechanisms for describing and explaining the structure of time-space emerged. When Einstein proposed a theory of time-space based on Riemannian geometry, and his theory was able to explain phenomena that Newtonian physics could not, rationalists could no longer argue that Euclidean geometry was the true representation of time-space. As well, developments in the area of particle physics early in the 20th century, started to undermine the belief that science could make any valid 'absolutist' claims.

As a result of the developments indicated, plus debate within philosophical circles, by the middle of the 20th century philosophical, psychological, and logical arguments caused most philosophers to conclude that proving or confirming anything in the absolutist sense was not possible (Nussbaum, 1989; Popper, 1951). However, this historical view of rationalism continued to be conveyed in science texts and science curricula long after it was considered untenable by philosophers. The term *logical positivism* is often used by critics of realism to refer to this historical realist position. Some writers (Eflin et al., 1999; Matthews, 1998) contend that, as a result of science education portraying an outdated view of realism, the current realist position has been seriously misrepresented.

Constructivist epistemology is the view that knowledge is created for its utilitarian value. While it is often referred to as alternative epistemological view, some writers contend that it is post-epistemological (Ernest, 1995; von Glasersfeld, 1992, 1995), since constructivism rejects the traditional epistemological distinction between knowledge and belief. As a result, von Glasersfeld (1992) prefers to refer to constructivism as a theory of knowing, as opposed to a theory of knowledge. Constructivist epistemology is sometimes associated with an instrumentalist ontology (Bodner, 1986; Matthews, 1998) or a coherence-based view of knowledge (Staver, 1998).

Wood (1995)indicates that in the constructivist view, knowledge is not a reflection of an ontology reality that is passively received, but rather a representation actively constructed by the learner. Constructed knowledge is useful and therefore viable when it allows the learner to function well in the environment. In the biological sense an organism is considered viable as long as it can survive and function within its environment. The constructivist notion of viability of knowledge is quite similar.

> To the constructivist, concepts, models, theories, and so on are viable if they prove adequate in the contexts in which they were created. Viability—quite unlike absolute truth—is relative to a context of goals and purposes. But these goals and purposes are not limited to the concrete or material. In science, for example, there is, beyond the goal of solving specific problems, the goal of constructing as coherent a model as possible of the experiential world (von Glasersfeld, 1995, p. 7-8).

From the constructivist view knowledge is not seen as true or untrue, but rather as viable or unviable, where viability of knowledge is determined based on how adequately it allows the knower to function in a particular environment. The constructivist view of environment includes not only the individual's physical surroundings, but also his individual understanding of that environment and the societal and cultural understandings that he or she is operating in as well.

To the constructivist, science is just a special kind of sensemaking. However, the goals of science require that knowledge produced as a result of its endeavor meet certain criteria (von Glasersfeld, 1995). These criteria comprise the accumulated and evolving beliefs about scientific thought held by scientists, philosophers of science, and sociologists of science. It is these beliefs that we refer to when we talk of individuals being socialized or encultured into the community of scientists. According to Driver (1989), "Learning science, therefore, is seen to involve more than the individual making sense of his or her own personal experiences but also being initiated into the 'ways of seeing' which have been established and found to be fruitful by the scientific community" (p. 482).

Within constructivism a range of positions have been identified. The two most frequently cited of these positions are referred to as radical constructivism and social constructivism. Radical constructivism traces its roots to Piaget and focuses on the cognitive processes involved as each of us subjectively constructs our experiential world (von Glasersfeld, 1995). Due to this individual focus, radical constructivism is sometimes referred to as cognitive constructivism.

Piaget (1985) postulated that a child's early language was egocentric speech and reflected internal, individual cognitive processes. Thus he viewed inner speech as assisting in concept organization and mediation. Social speech. in Piaget's view, developed later and was used for communication (Fosnot. 1996). Thus in radical constructivism the process of knowing is deemed to occur in the individual mind of the learner.

Social constructivism, while having much in common with radical constructivism, is more closely associated with Vygotsky. While the work of Piaget and of Vygotsky is generally considered to be complimentary and/or compatible, there are some areas of disagreement. The most notable of these involves the role of language in concept formation and the role of inner speech in this process (Fosnot, 1996). Vygotsky viewed inner speech as being social from its conception. Thus he contended that concept formation begins as a social process which later becomes internalized. For Vygotsky, concept formation is a social process facilitated through language, communication and culture, with inner speech developing later than social speech. Those constructivists who follow Vygotsky's arguments, conclude that knowledge is actually held in the social and cultural interactions of the group, rather than in the minds of the individuals who constitute the group. Thus a dispute exists between radical constructivists who give primacy to internal individual processes and social constructivists who give primacy to social and cultural processes (Cobb, 1996).

It has been argued, however, that both types of constructivist knowing, individual and social, can only exist within the context of the other. Therefore, Cobb (1996) opines that a forced choice between radical and social constructivism is an arbitrary one, and we would be better off to envision learning as "both a process of active individual construction and a process of enculturation into...practices of the wider society" (p. 35). Cobb contends that arguments about primacy are irrelevant and fruitless, since, depending on one's assumptions, one perspective simply forms the background for the other. Tobin and Tippin (1993) argue that the synthesis position is that, "knowledge is personally constructed but socially mediated" (p. 6).

Constructivist epistemology, then, rejects realist ontology and views the active construction of knowledge as a process that allows individuals to interpret sense impressions in order to function within a particular environment. While radical and social constructivists may differ on their views of the individual versus social nature of knowledge, the key features of both are very similar.

Closely associated with constructivist epistemology is constructivist learning theory. Constructivist learning theory can be described as the belief that the learner actively constructs meaning from the environment as he or she attempts to make sense of the world. This perspective holds that meaningful learning takes place in the mind of the learner as the result of the interaction between sense impressions and the learner's previous understanding (Appleton, 1993; Driver, 1981; Fosnot, 1996; Saunders, 1992). For constructivists, making sense of the world involves the application of the learner's existing concepts to help explain new phenomenon. However, in the process the conceptual framework of the learner may be altered to better account for what he or she perceives. Saunders (1992) defines constructivist learning theory as:

> the notion that learners respond to their sensory experiences by building or constructing in their minds, schemas or cognitive structures which constitute the meaning and understanding of the world. Individuals attempt to make sense of whatever situation or phenomenon that they encounter, and as a consequence of this sense making process (a process which takes place in the mind of these individuals) is the establishment of structures in the mind. (p. 136)

Constructivist learning theory is now accepted as a fundamental component of current science curriculum development activities (AAAS, 1989,1993; APEF, 1998; CMEC, 1997; Matthews, 1998; Staver, 1998). Even critics of constructivist epistemology have acknowledged the benefits that have been accrued through the application of constructivist learning theory to science education (Matthews,1998; Staver, 1998). However, debate still rages around the issue of which epistemological position(s) should be used as the basis for this learning theory and which view(s) of the nature of science should be reflected in the curriculum. Hodson (1991) indicates that the fundamental issue of which view of the nature of science, realism or instrumentalism, will be portrayed in the curriculum has yet to be resolved.

Many science curriculum writers have been critical of the vision of the nature of science portrayed in existing science education (Larochelle & Desautels, 1991; Lederman, 1992; Nadeau & Desautels, 1984; Ryan & Aikenhead, 1992). Leach et al. (1997) conclude that:

> Within school science classrooms, the image of science that tends to be portrayed is of individuals seeking true knowledge through empirical enquiry....The image of the generation of scientific knowledge presented is one of individuals seeking explanations through a process of empirical testing and evaluation. This empiricist, individualistic view of scientific knowledge and the scientific enterprise has been heavily criticized by historians, philosophers and sociologists of science on several grounds: it is not possible to collect data in a value free way; observations are always made in the context of theory...; the logic involved in proving an inductive knowledge claim itself relies on induction...; individual knowledge claims only become accepted knowledge through a social process involving the community of scientists....Contemporary perspectives on the nature of the scientific enterprise recognize the contribution of human imagination and social processes. Some would argue that there is no single 'nature of science' (p. 147–148).

Nadeau and Desautels (1984) argue that it not possible to teach science without conveying messages about the nature of science. They also contend that traditional content-focused science curricula have misrepresented the nature of science. Nadeau and Desautels (1984) labeled this misrepresentation *scientism* and described it as being comprised of five myths common to traditional science education. These are:

1 Naïve realism: Scientific knowledge is the reflection of things as they really are.
2 Blissful empiricism: All scientific knowledge derives directly and exclusively from observation of phenomena.
3 Credulous experimentalism: Experimentation makes possible conclusive verification of hypothesis.
4 Blind idealism: The scientist is a completely disinterested, objective being.
5 Excessive rationalism: Science brings us gradually nearer the truth.

Nadeau and Desautels (1984) contend that the portrayal of these myths in science courses is the result of giving insufficient thought and attention to the nature of science in the curriculum. The authors argue that science curricula, especially at the high school level, should examine the conditions that engender scientific learning and instill in students a critical approach to science. Many writers express similar concerns (Aikenhead, 1979, 1987; Hodson, 1988; Reeves & Ney, 1992; Roth & Roychoudhury, 1993, 1994; Ryan & Aikenhead, 1992) and conclude that science education should change the manner in which it represents science. This change in curriculum focus is closely associated with the STS movement and the adoption of scientific literacy as the major goal of science education. The AAAS (1989) publication, *Science for All Americans*, has been the main springboard for this curriculum reform.

While Nadeau and Desautels (1984) and AAAS (1989) originally called for the portrayal of a more current, defensible and skeptical view of science in the curriculum than logical positivism, some researchers and science educators have gone beyond this and argue for the explicit and exclusive use of an instrumentalist ontology and a constructivist view of the nature of science in science curricula (Aikenhead, 1979, 1987; Driver et al., 1996; Hodson, 1988; Reeves & Ney, 1992; Roth & Roychoudhury, 1993, 1994; Ryan & Aikenhead, 1992; Staver, 1998). With the rise of constructivist learning theory, instrumentalist ontology and constructivist epistemology have become the dominant positions within the science education community (Matthews, 1998). The debate between realists and constructivists has been at times heated, with constructivists arguing that realist ontological positions are untenable and realist arguing that constructivist epistemology requires a descent into relativism. Matthews (1998) points out that much of this debate, however, is misplaced, "because both sides attribute to the other positions that are not held" (p. 166). Eflin et al. (1999), three philosophers of science, voice a similar concern. They state that, "From the sources that we have seen, it appears that the position science educators call logical positivism is a straw man position held by at most a few philosophers, and only for a short period of time 70 years ago" (p. 114). They argue that misrepresentation of the current realist position in the science education literature has resulted in calls for the elimination of references to realist epistemology and the exclusive use of constructivist views of the nature of knowledge in the science curriculum (Eflin et al., 1999; Matthews, 1998). Others constructivist writers offer a different rationale for embracing constructivist epistemology. Staver (1998), for example, argues that the use of constructivist epistemology in science curriculum maximizes the benefits of constructivist approaches to learning and teaching. He concludes that the exclusive use of constructivist epistemology is justified since it constitutes a viable position within philosophy of science and its use may result in improved student learning.

Matthews (1992) disagrees. He argues that the philosophical underpinnings of most forms of constructivism are, in fact, empiricist in nature. He contends that there are two fundamental theses of constructivism: (1) that knowledge is not passively received, but is actively constructed by the cognizing individual, and (2) the function of cognition is adaptive and serves the purpose of organizing one's experiential world, not the function of discovering an ontological reality. Constructivists take care to point out that the cognizing individual is not attempting to make sense of reality, but rather of sense impressions (Staver, 1998). However, the metaphors and examples that are used by constructivists, and Matthews cites many, all imply or describe an individual examining some phenomenon through the use of the senses. Matthews concludes that, "Any epistemology which formulates the problem of knowledge in terms of a subject looking at an object and asking how well what they see reflects the nature or essence of the object is quintessentially...empiricist" (1992, p. 189). According to Matthews, empiricism and constructivism both conceive "the enterprise of science in terms of individuals looking at the world and trying to ascertain whether their ideas, concepts, and conceptualizations make sense" (1992, p. 193).

Staver (1998) argues that realism is untenable because of the root paradox. He further argues that since constructivism is based on a coherence, rather than a correspondence theory of truth, it avoids the root paradox. He states, "Constructivism is not a theory of being; rather, it is a theory of knowing. Constructivism is silent with respect to ontology, be it realist, idealist, or otherwise" (Staver, 1998, p. 515). Staver does not clarify if being "silent" with respect to ontological issues means that constructivists do not consider ontological issues because they are pointless, or if constructivists are free to choose whichever ontological commitment they desire. Staver concludes that constructivist science and realist science have much in common. He suggests that science simply give up the goal of discovering an ontological reality and instead buy into the constructivist paradigm. By opting for truth as internal coherence. he argues, science is better off:

> Free of ontology and the root paradox, science in a constructivist perspective is also free of traditional philosophical arguments about empiricism, instrumentalism, and relativity, at least in the sense that such arguments are based on truth as correspondence. Instead, constructivism offers science a more parsimonious paradigm of knowing as an adaptive function within a biological context, with the purpose of coping with our experiential world, and language-based social interaction as a mechanism for achieving knowledge in communities....The empirical character of science, as expressed in the thoughts and actions of scientists who seek to know, to bring coherence to our individual experiential worlds and collective knowledge through observation, experimentation, and the adjudication of results and theories needs no change within a constructivist framework (Staver, 1998, p. 517).

Matthews (1998) also concludes that constructivist science and realist science have much in common. He states:

> Most realists are sophisticated about science and its history. They recognize that science is a human creation, that it is bound by historical circumstances, that it changes over time, that its theories are underdetermined by empirical evidence,

> that its knowledge claims are not absolute, that its methods and methodology change over time, that it necessarily deals with abstractions and idealizations, that it involves certain metaphysical positions, that its research agenda are affected by social interests and ideology, that its learning requires that children be attentive and intellectually engaged, and so on. These are positions that both sides can happily agree about and can encourage students to appreciate. If these positions collectively amount to constructivism, then we are all constructivists—although, as von Glasersfeld remarked on one occasion, this is *trivial* constructivism.
>
> The differences begin to emerge at the next level. Realists believe that science aims to tell us about reality, not about our experiences; that its knowledge claims are evaluated by reference to the world, not by reference to their personal, social, national utility; that scientific methodology is normative, and consequently distinctions can be made between good and bad science; that science is objective in the sense of being different from personal, inner experience; that science tries to minimize the impact of non-cognitive interests...in its development; that decision making in science has a central cognitive element that is not reducible to mere social considerations, and so on (Matthews, 1998. p. 166).

In essence, both Staver (1998) and Matthews (1998) agree on many issues except what the goal of science should be. Staver argues for the adoption of a constructivist perspective because this would allow us to ignore ontological issues while uniting epistemology of science, the practice of science. learning theory. and science curriculum under the constructivist banner. Matthews disagrees and contends that science represents an attempt to know the universe at it really exists, not simply as we perceive it.

Matthews (1998) points out that views of the nature of science are in dispute and that constructivist positions have been challenged and disputed by scholars both inside and outside of the field of education. Therefore, he expresses concern that portraying any one aspect of the nature of science would misrepresent the field. While Staver (1998) argues that constructivism can be considered to be neutral with respect to ontology, Matthews expresses concern that representing exclusively constructivist epistemology in the curriculum would result in support for more relativist positions. He states that, "Constructivism is at its core, as it was with Piaget, an epistemological doctrine; and it is standardly coupled with commitments to certain postpositivist, postmodernist, antirealist, and instrumentalist views about the nature of science" (Matthews, 1998, p. 165). Matthews argues that dealing in an open and critical way with modest issues in epistemology is preferable to positing one official position and requiring that students adhere to it. He states, "There is a danger that teachers, curriculum developers, and examiners will define 'epistemological development' merely as 'believing what I believe about epistemology.' When this happens we confuse education with indoctrination" (p. 167).

Meyling (1997), like Matthews (1998), argues for a pluralistic approach to the treatment of the nature of science in the curriculum. Both Lederman (1995) and Smith and Scharmann (1999) argue that current research shows high school students to be at a dualistic stage of intellectual development and are therefore unable to hold one view of the nature of science while trying to understand another. Therefore, they contend that a pluralistic approach to the nature of science is not desirable.

Both Alters (1997) and Smith and Scharmann (1999) agree with Matthews' point that many issues regarding the nature of science are in dispute. Alters offers no suggestions for classroom practice, however, he is critical of researchers who define a constructivist position as being more developed or appropriate than others. He advocates the development of instruments to assess understanding of the nature of science that address the plurality of positions regarding the field and suggests that some common ground regarding the nature of science should be investigated.

Abd-El-Khalick, Bell, and Lederman (1998) contend that advanced topics in philosophy of science, such as ontology, should not be considered for inclusion in the K–

12 curriculum because they are too abstract for students to understand and of no immediate consequence to their lives anyway. Eflin et al. (1999) and Smith and Scharmann (1999) also share this view. Abd-El-Khalick et al. also contend that there are aspects of the nature of science that are both understandable by students and relevant to their daily lives. They identify the following aspects as meeting these criteria:

> Scientific knowledge is tentative...; empirically based...; subjective...; partly the product of human inference, imagination, and creativity...; and socially and culturally imbedded. Two additional important aspects are the distinction between observations and inferences, and the function of, and relationships between scientific theories and laws (p. 418).

Smith and Scharmann argue a similar position. They contend that the goal of science education should not be to have students accept or reject a particular theory. Rather, they argue that we should attempt to develop students who are capable of understanding theories, of evaluating the evidence for and against particular theories, and consequently understanding why scientists would accept or reject a theory. Eflin et al. (1999) offer a similar moderate proposal and contend that their suggestions resemble the elements of the nature of science originally identified in the AAAS (1989) publication. Science for All Americans.

Duschl, Hamilton, and Grandy (1990) appear to be speaking for the vast majority of science educators when they assert that concept acquisition in science requires that teachers deal with epistemological issues. However, Duschl et al. indicate that intellectual debates about the nature of science are not useful to practicing teachers and argue that, "if we are to have teachers employ epistemological rules in teaching science, then philosophers of science must come to considerably more agreement about what those rules are" (p. 242). It would appear that there are essentially two responses to their request. One response, or rather, the response from one group, is that constructivist epistemology is a valid and widely accepted stance that can be used to maximize student learning of concepts in science. Therefore constructivist epistemology should be explicitly and exclusively represented in the science curriculum. While some within this group seek to attach constructivist epistemology to relativist positions, others avoid ontological issues. The majority of respondents in this group appear to be science educators, rather than philosophers of science. The second response, or rather, the response from the second group, is that many aspects of the nature of science are under dispute and to simplify the situation by including only one view would be irresponsible. This group is comprised primarily of individuals who are more closely related to philosophy of science than science education. The minority position within this group appears to be that students should be given exposure to both realist and instrumentalist views of science in the curriculum. The majority view appears to be to stake out some middle ground that both sides can agree on and that will not result in indoctrination of students into any particular camp with respect to ontology and epistemology. Writers on both sides have attempted to identify aspects of this middle ground.

General Epistemology

Psychological research on epistemological development began in the last half of the 20th century. Most of this research involved students who were either in late adolescence (high school) or early adulthood (university). The first substantial model, posited by Perry (1970) was based on a longitudinal study of the epistemological development of liberal arts undergraduate students as they progressed through Harvard and Radcliffe in the late 1950s and early 1960s. Perry's work culminated in the production of a nine-stage scheme of intellectual and ethical development that described college students' transition from dualism, through multiplicity, relativism, and eventually into a form of contextual relativism. Perry (1970) described his nine positions as follows:

> *Position 1:* The student sees the world in polar terms of we-right-good vs. other-wrong-bad. Right Answers for everything exist in the Absolute, known to Authority whose role is to mediate (teach) them....
> *Position 2:* The student perceives diversity of opinion, and uncertainty, and accounts for them as unwarranted confusion in poorly qualified Authorities or as mere exercises by Authority "so we can find The Answer for ourselves."
> *Position 3:* The student accepts diversity and uncertainty as legitimate but still *temporary* in areas where Authority "hasn't found The Answer yet." ....
> *Position 4:* (a) The student perceives legitimate uncertainty (and therefore diversity of opinion) to be extensive and raises it to the status of an unstructured epistemological realm of its own in which "everyone has a right to his own opinion," a realm which he sets over against Authority's realm where right-wrong still prevails, or (b) the student discovers qualitative contextual relativistic reasoning as a special case of "what They want" within Authority's realm.
> *Position 5:* The student perceives all knowledge and values (including Authority's) as contextual and relativistic and subordinates dualistic right-wrong functions to the status of a special case, in context.
> *Position 6:* The student apprehends the necessity of orienting himself in a relativistic world through some form of personal Commitment (as distinct from unquestioned or unconsidered commitment to simple belief in certainty).
> *Position 7:* The student makes an initial Commitment in some area.
> *Position 8:* The student experiences the implications of Commitment, and explores the subjective and stylistic issues of responsibility.
> *Position 9:* The student experiences the affirmation of identity among multiple responsibilities and realizes Commitment as an ongoing, unfolding activity through which he experiences his life style (p. 9–10).

Critical of Perry's use of predominantly male subjects, Belenky, Clinchy, Goldberger, and Tarule (1986) conducted similar research, but included only female subjects. The researchers argued that a developmental scheme arrived at through the use of predominantly male subjects should not be used as the norm for both males and females. This research was an epistemological parallel to Gilligan's (1982) work on moral development. Gilligan argues that such practice leads to females being judged as deficient when viewed against male norms. The Belenky et al. research also differed from Perry's (1970) in that the latter focused on the nature and status of knowledge, whereas Belenky et al. dealt more with the sources of knowledge and the relationship between the knowledge and the knower.

Based on the study of 135 women, some still enrolled in post-secondary institutions and some not, Belenky et al. (1986) put forward a "set of epistemological perspectives from which women know and view the world" (p. 3). The five perspectives outlined by Belenky et al. were: silence, received knowledge, subjective knowledge, procedural knowledge, and constructed knowledge. While Perry's (1970) work had been the result of a longitudinal study, Belenky et al. used a cross-sectional design. Consequently, the resulting scheme was not presented as a set of stages, however, developmental patterns can be inferred from it.

Based on a longitudinal study of 101 randomly selected students from the University of Miami (Ohio), including a gender balance, Baxter Magolda (1992) put forward a scheme of epistemological positions. She identified four basic types of knowers: absolute knowers, transitional knowers, independent knowers, and contextual knowers. Within her scheme there were also some gender-related subdivisions. Absolute knowers were classified into two types, mastery and receiving. Mastery knowers were predominantly men and receiving knowers were predominantly women. Transitional knowers were classified into two types, impersonal and interpersonal. Impersonal knowers were predominantly men and interpersonal knowers were predominantly women. Independent knowers were also classified into two types, individual and interindividual. Individual knowers were predominantly men and interindividual knowers were predominantly women. The final level, contextual knowers (constituting only a small minority of the subjects), did not exhibit the same sort of gender patterns found in the previous levels. Baxter Magolda's scheme strikes an interesting balance between the Perry (1970) and Belenky et al. (1986) research since it recognizes the existence of different gender perspectives, yet still offers a universal framework.

King and Kitchener's (1994) model of epistemological development centers on reflective judgement in problem-solving situations. Their seven-stage developmental model includes three basic levels: pre-reflective (stages 1–3), quasi-reflective (stages 4 & 5), and reflective (stages 6 & 7). This structure was the result of several studies (King & Kitchener, 1994; King, Kitchener, Davison, Parker, & Wood, 1983; Kitchener & King, 1981; Kitchener, King, Wood, & Davison, 1989), some using cross-sectional designs and others longitudinal, which examined how individuals engage in ill-structured problem solving. Their research found relationships between age and epistemological stage as well as between education and epistemological stage (King & Kitchener, 1994; Kitchener & King, 1981).

Schommer (1990, 1993) questions the viewpoint that individuals' epistemological positions are one-dimensional. She contends that there are four more or less independent dimensions to epistemology. Each of Schommer's dimensions or factors is viewed as a continuum, however, they are typically stated from the naïve perspective. The *Certain Knowledge* factor assesses students' views on knowledge as certain (naïve) versus knowledge as tentative and evolving. The *Simple Knowledge* factor assesses students' views on knowledge as isolated and unambiguous bits (naïve) versus knowledge as a highly integrated set of concepts. The *Quick Learning* factor assesses students' views on whether learning occurs quickly or not at all (naïve) versus believing that learning occurs slowly. The *Fixed Ability* factor assesses students' views on whether intelligence is a fixed entity (naïve) versus believing that it can be improved. Schommer has hypothesized that a fifth factor, *Source of Knowledge*, would range from authority (naïve) to reason.

The bulk of Schommer's work has investigated how this model of epistemological beliefs interacts with other factors, such as gender, grade level, and academic achievement. For example, based on her study of 1182 high school students (grades 9–12) Schommer (1993) concluded that female students were less likely to believe in fixed ability or quick learning. Students also advanced in their epistemological development over the course of high school, with higher grade levels associated with believing less in simple knowledge, quick learning, and certain knowledge. Epistemological beliefs were also related to academic performance, with students who believed less in quick learning more likely to have a higher GPA.

While there is disagreement about many facets of epistemological development, the literature documents the development of epistemological views as individuals move from an absolute and authoritative view of knowledge to a more tentative and contextual view of knowledge. According to Hofer and Pintrich (1997):

> Most of those who have studied epistemological beliefs have concluded that there is some developmental progression of those beliefs in the movement to adulthood, particularly for those who experience a college education....In spite of the various approaches, methodologies, samples, and designs, there is agreement across studies as to the general trend of development. Within these models it appears that the view of knowledge is transformed from one in which knowledge is right or wrong to a position of relativism and then to a position in which individuals are active constructors of meaning, able to make judgements in a relativistic context (p. 121).

Little research in epistemology has focused on childhood and early adolescence. One explanation for the dearth of epistemological research on children is the inference, drawn from early studies, that little epistemological development occurs before adulthood (Hofer & Pintrich, 1997). Hofer and Pintrich state that, "There is clearly a positive relation between age and education and epistemological development, but it is unclear where the process of epistemological development begins, as few studies exist below college level, and fewer yet before high school" (p. 122). Perry's work is sometimes used to support the notion that epistemological development is limited to adults (Carey et al., 1989). However, Perry (1970), does not appear to have made this claim. He indicated that no students held position 1 structures when first interviewed at the completion of their freshman year. Perry stated that:

> A few did attempt to describe themselves as having arrived at college in just such a frame of mind. but none could have remained in it and survived the year. Position 1 is therefore an extrapolation generated by the logic of the scheme. At the end of the year, freshman normatively expressed the outlooks of positions 3, 4, or 5 (p. 55–56).

Chandler (1987) criticizes what he describes as the "commonly held conviction" that little epistemological development occurs before adulthood. He does not dispute that the research has shown epistemological development in college students and adults, however, he argues that these sorts of epistemological views are obtainable with older adolescents. While some research has demonstrated that the high school years are not devoid of epistemological development (Schommer, 1993), the literature generally assumes that children and early adolescents hold naïve realist views of knowledge. For example, Carey et al. (1989) summarize the literature as follows:

> Young adolescents make no differentiation between beliefs and the world, between accounts of the world and the world itself, between knowledge and

> reality. Differences of opinion are either not recognized or assumed to reflect differential access to information; the only mechanism that could yield incorrect beliefs is ignorance. In late adolescence, people become aware of genuine differences in interpretation of the same facts, genuine differences in beliefs. This leads to a period of radical relativism—there is no true knowledge and everybody is free to believe whatever they want. Finally, some people reach a mature epistemology that recognizes the relativity of belief to interpretive frameworks, but also recognizes that there are some canons of rational justification of belief (p. 516–517).

From a general epistemological position, then, the literature implies that young adolescents are naïve realists with an absolute view of knowledge. Justification for knowledge is either not required or held solely on the basis of authority. Epistemological progress from this position or stage appears to be related to age and life experiences, with formal education being a significant form of the latter. The research base for this position is limited, with some writers suggesting that this is an inferred position based on studies involving older adolescents and adults.

Students' Understanding of the Nature of Science

References to the nature of science as a science curriculum topic have appeared throughout the 20th century (Central Association of Science and Mathematics Teachers, 1907; Lederman, 1992). However, increased emphasis in this area began in the 1960s culminating in the inclusion of the nature of science as a key topic in the scientific literacy curriculum focus that has predominated in North America over the last 20 years (AAAS, 1989, 1993; CMEC, 1997; NRC, 1996). Attempts to determine students' understanding of the nature of science have developed as a natural extension of this curriculum focus (Lederman, 1992).

Early attempts at determining students' views on the nature of science involved primarily high school students and used predominantly surveys and questionnaires. Recent studies have tended to use more open-ended methods such as interviews to examine students' views of the nature of science and have often involved multiple data sources.

Wilson (1954) used the Science Attitude Questionnaire (SAQ) in a study of 43 Georgia high school students. Results from the study indicated that the students considered scientific knowledge to be absolute and that the main goal of scientists was to discover natural laws and truths. Klopfer and Cooley (1961) developed the Test of Understanding Science (TOUS). Results from a number of studies based on the TOUS agreed with the conclusion that students held poorly developed views of the nature of science (Mackay, 1971; Miller, 1963). Mackay's study of 1,203 Australian secondary school students (grades 7–10) concluded that students held inadequate views of, among other things: the role of creativity in science; the function of scientific models; the role of theories and their relation to research; the distinctions among hypotheses, theories, and laws; the relationship between experimentation, models and theories, and absolute truth; and what constitutes a scientific explanation (Mackay, 1971).

Kleinman (1965) using the TOUS–Jy, a version of the TOUS adapted for use with junior high school students, concluded that most of the 849 seventh and eighth grade students involved in the study held inadequate views of the nature of science. The large majority of students failed to identify the main goal of science as explaining and describing "natural phenomena in terms of principles and theories" (p. 315). The majority of students also failed to identify the hypothesis-testing nature of scientific experimentation.

Lederman's (1986) study of 18 classes of grade 10 biology focused on teaching behaviors and classroom climate that related to changes in students' conception of the nature of science. Lederman administered the NSKS developed by Rubba and Anderson (1978) as a pre- and post-test to students enrolled in a one-semester biology course. Average values were calculated for each class on each of the NSKS subscales as well as the NSKS overall. While the pre-test results indicated that the students, on average, scored above the midpoint of the NSKS, the author considered the scores to be "extremely similar and moderate" (Lederman, 1986, p. 6), indicating that these students held views consistent with those reported in previous research.

Lederman and O'Malley (1990) investigated 69 high school students' (grades 9–12) views regarding the tentativeness of scientific knowledge using an open-ended questionnaire developed for the study. The authors selected this aspect of scientific knowledge for several reasons. They stated:

> Research concerned with the nature of science as an instructional outcome has primarily focused on students' understanding of the tentative and revisionary aspects of scientific knowledge. Attention to this aspect of scientific knowledge (by researchers and curriculum developers) has been based on the belief that tentativeness is the primary attribute of scientific knowledge and that an understanding of this characteristic is achievable by students at all age levels (Lederman & O'Malley, 1990).

Twenty of the 69 subjects were selected to participate in further interviews. The selection process was designed to identify subjects who were highly verbal and who were reflective of the grade levels involved. Based on the questionnaire results, students were chosen based on whether or not they held tentative versus absolute views of science, and whether or not those views had changed during the course of the study. Students from the extreme groups were then selected to participate in interviews. After comparing the questionnaire results to the interviews the authors concluded that the two contradicted each other, as all of the students who were classified as absolutists indicated during the interview that they held a much more revisionary and tentative view of scientific knowledge than was interpreted from the questionnaire results. The differing results, hinged on the students' use and understanding of what it means to "prove" a theory in science. In attempting to explain the results, Lederman and O'Malley (1990) argued that the concept of tentativeness in science is a complex one that cannot be captured in a few words or phrases and is therefore difficult to assess in survey instruments.

Larochelle and Desautels (1991) investigated the views of 25 students aged 15–18 who had completed, on average, six high school science courses. Their results indicated that students held predominantly naïve realist positions with respect to the nature of scientific knowledge, yet demonstrated more sophisticated views in other epistemological areas. Results of their semi-structured interviews suggested that it was difficult to distinguish between students' views of science and their views of school science curriculum. The authors concluded that the students held positions that were predominantly naïve realist and empiricist in nature, knowing little of the tentative, revisionary status of knowledge and the "reflective, conflictual and unfinished character" (Larochelle & Desautels, 1991, p. 387) of knowledge production. Stated one subject:

> Scientific knowledge is always the same thing. Scientific knowledge is always F = ma. It is a formula, it is always the same. While religious studies...can be affected by your family: if you were born Catholic, you will believe in the Catholic religion. It depends on your nationality, it depends on what you have lived through, of society. [While scientific knowledge] if it is true, it is also true for the working class. I think that an apple is an apple and when it falls, it always falls with an acceleration of 10 metres per second square: the Martians would also find that (Larochelle & Desautels, 1991, p. 382).

Roth and Roychoudhury (1994) investigated the views of the nature of science held by 42 high school students enrolled in an introductory physics course at a private all-male school in central Canada. Their study examined samples of students' writing as well as conducting an interview and a preferred classroom environment inventory. For their research they defined two opposing views of the nature of knowing and learning—objectivism and constructivism. Their results indicate that the students held predominantly objectivist views with respect to the nature of scientific knowledge, its truth value, and its independence from human existence. As well, the majority of students held objectivist views with respect to learning science. However, many students held constructivist views regarding the social influence on scientific knowledge, despite the fact that they held objectivist views of the nature of scientific knowledge itself.

The results of studies involving high school students' understanding of the nature of science generally indicate that they do not view science as a creative endeavor (Mackay, 1971), tend not to identify the explanatory function as being central to science (Mackay, 1971), and tend to consider scientific knowledge to be absolute and static (Wilson, 1954) rather than tentative (Larochelle & Desautels, 1991). Larochelle and Desautels hypothesize that high school students' views of the nature of science may be related to the didactic nature of high school science classrooms.

With respect to epistemology of science, few studies have focused on early adolescents. Inhelder and Piaget (1958) concluded that children below ages 13 to 15 are not generally able to evaluate hypotheses because they lack the understanding of logic required to do so. Later work by Kuhn and Phelps (1982) indicated that 10- and 11-year olds had significant difficulty with a science investigation that they were asked to perform. They concluded that the students' experimentation was unsystematic and often resulted in invalid conclusions. Kuhn, Amsel, and O'Loughlin (1988) asked subjects aged 8, 11, and 14 years, and adults to generate and evaluate evidence related to a phenomenon. Subjects of all ages had difficulty determining whether a particular set of data supported, refuted, or had no bearing upon the theory in question. However, the 8- and 11-year olds were unable to generate (invent) data which would be disconfirming of their theory. The authors concluded that students of this age could not or did not differentiate between the notions of theory and evidence and therefore could not conceptualize evidence as separate from the theory.

Carey et al. (1989) investigated the views of the nature of science and scientific knowledge held by 65 grade seven students from the Boston area. Following an analysis of semi-structured interviews of 27 of the students, a classification scheme was developed and the students were classified based on their epistemological positions across a set of six domains.

> Three general levels of response were identified. In level 1, the students made no clear distinction between ideas and activities, especially experiments. A scientist "tries it to see if it works." The nature of "it" remained unspecified or ambiguous; "it" could be an idea, a thing, an invention, or an experiment. The motivation for an activity is the achievement of the activity itself, rather than the construction of ideas. The goal of science is to discover facts and answers about the world and to invent things.
>
> In level 2, students make a clear distinction between ideas and experiments. The motivation for doing experiments is to test an idea to see if it is right. There is an understanding that the results of an experiment may lead to the abandonment or revision of an idea; however; there is yet no appreciation that the revised idea must now encompass all the data—the new and the old. The goal of science is understanding natural phenomena—how things in the world work.
>
> In level 3, as in level 2, students make a clear distinction between ideas and experiments, and understand that the motivation for experiments is verification or exploration. Added to this is the appreciation of the relation between the results of an experiment (especially unexpected ones) and the idea being tested. Level 3 understanding recognizes the cyclic, cumulative nature of

> science, and identifies the goal of science as the construction of ever-deeper explanations of the natural world (p. 520–521).

In their scoring scheme Carey et al. (1989) allowed for a score of zero (0) which indicated that the student seemed "not to consider the information-seeking aspects of science at all" (p. 521). The majority of the grade seven students scored in the level 1 range across all six domains in both the pre-test and post-test, with only four of 27 students having overall mean scores over 1.5 on the pre-test and none achieving a 2.0. The major feature of a level 1 score was that it indicated that the student had no "appreciation that ideas are distinct, constructed and manipulable entities" (Carey et al., 1989, p. 521). The level 1 designation also meant that the student had "no understanding that a scientist's ideas motivate the scientist's other, more tangible work, such as gathering data and doing experiments, or that the ideas, in turn, are affected by this work. Instead, ideas are confused with experiments, or whatever else they are about" (p. 521). Scientists were also seen to be discovering facts and knowledge that existed out in the world. There was no comprehension that ideas were about natural phenomenon.

Songer and Linn's (1991) research involved 153 eighth-grade students from California. The research investigated students' understanding of the nature of science using questionnaires, tests, and interviews. Students were classified into one of three groups (Dynamic, Static, and Mixed) based on their views of the nature of science. Fifteen percent of the students were classified as having dynamic views of science. The authors indicate that students with dynamic views of science, "recognize that scientific knowledge is controversial. These students realize that scientists compare results and that scientists can look at the same experiment and reach different conclusions. Students in this group also believe that scientists use evidence to resolve controversy" (p. 772).

Twenty-one percent of the students involved in the study were classified as having static views of science. These students considered science to be a straightforward accounting of individual facts and ideas that do not change. The majority of students (63 %) held mixed views of science, with some survey responses showing dynamic views and others static.

Meichtry (1992) also investigated early adolescent students' views of the nature of science. She used the Modified Nature of Scientific Knowledge Scale (MNSKS), a subset of the NSKS developed by Rubba and Anderson (1978), to assess 1300 students' understanding of the nature of science. The MNSKS was based on a four-factor model of the nature of science that determined scientific knowledge to be creative, developmental, testable, and unified. Meichtry (1992) found that the average scores on each subscale and overall on the MNSKS for the sixth, seventh, and eighth graders involved in her study fell below the midpoint. She interpreted these results to mean that the students' views were generally inconsistent with the four-factor model of the nature of scientific knowledge used in the study and concluded that, "the students who participated in this study did not believe that scientific knowledge is partially a product of human creativity, tentative, capable of empirical test, or that the specialized sciences contribute to a network of interrelated laws, theories, and concepts" (p. 395). Rather, the author concluded that the students held more traditional, absolutist views of the nature of science.

Solomon, Duveen, and Scott (1994), working with 11–14 year olds from three British schools, investigated students' images of science and whether or not historical vignettes illustrating aspects of the nature of science would affect these images. The study involved pre- and post-course questionnaires and interviews, as well as interviews throughout the year. The authors reported that some pupils had almost no idea how to answer questions relating to the nature of science, indicating that students' understanding of science and epistemology of science was so weak that they had difficulty answering or discussing the questions. Solomon et al. categorized students descriptions as capturing various "images" of science and constructed seven categories of description, each with a title and an epistemological position (see Table 1). They also indicated that many students articulated more than one of these images.

Table 1

The Seven Images of Scientists (Solomon et al., 1994)

Character	**'Epistemology'**
Cartoon	No expectation. Dangerous and surprising experiments.
Vivisectionist	No expectation. Testing. Hurts and kills animals.
Authoritative	All known and certain. All experiments performed yielding correct results=knowledge.
Technologist	Outcomes are useful artifacts. Tests 'if they work' and makes them 'better'.
Teacher	Knowledge certain. Experiments are repeated.
Pupil	Right answers exist, but experiments 'don't work'.
Entrepreneur	Search for new knowledge and valuable products. Competition and secrecy, technologists.

The column labeled "epistemology" referred to expectations about results of experiments, followed by other epistemological references. Many students indicated that scientists had no idea what would happen in experiments. According to one student, "They [scientists] don't know what's going to happen. That's why they experiment." Solomon et al. (1994) referred to this as the "cartoon view of mindless experiment" (p. 366). Comparison of pre- and post-test questionnaire results indicted that significant changes occurred with respect to students' understanding the purpose of experiments, with post-test results indicating students more likely to relate experiments to evaluating explanations. The authors noted, however, that this statistical change was not accompanied by the same magnitude of change in the interviews and other qualitative data. In fact, they comment about the "worryingly little evidence from the interviews about the 'explanation' of phenomena" (Solomon et al., p. 368). This was most apparent when students were given a task that asked them to describe and explain situations based on science units that they had just completed. The majority of the Year 7 (grade 6) students failed to distinguish between descriptions of a phenomenon and explanations for that phenomenon. The authors contended that this lack of differentiation between description and explanation has been noted in the literature previously (Piaget, 1926; Solomon, 1986).

Tsai (1998) compared Taiwanese 202 eighth grade students' epistemological beliefs (SEB) about science with their learning orientation. The subjects were all above average academic achievers. The author used Pomeroy's (1993) five-point Likert scale questionnaire to stratify the initial sample into students who had empiricist versus constructivist views of scientific knowledge. Only students who indicated that they were "fairly certain" or "confident" of their answers to more than 75% of the questions on the Pomeroy questionnaire were considered for inclusion in the remainder of the study. The final sample included six students randomly chosen from the top 15% based on the Pomeroy results, six randomly chosen from the bottom 15%, plus eight students chosen to represent the mean or average position. The author described the empiricist position as follows:

> (1) scientific knowledge is unproblematic and it provides *right* answers; (2) scientific knowledge is *discovered* by the *objective* data gathered from observations and experimenting or from an universal scientific method; (3) scientific knowledge is additive and bottom-up, and evidence accumulated

carefully will result in infallible knowledge (Tsai, p. 474–475).

The constructivist views "assert that scientific knowledge is *constructed* (or *invented*) by scientists, its status is tentative, and its development experiences a series of revolutions or paradigm shifts" (Tsai, 1998, p. 475). While both constructivist and empiricist students agreed that scientific knowledge changed over time, Tsai reports that the reasons for doing so varied with the two groups. She states that empiricist students tend to attribute differences in scientists' theories to differential access to knowledge or to errors. Empiricist students also tend to believe that there is only one correct or valid explanation for a phenomenon. Conversely, Tsai concludes that constructivist students "tended to believe that the existence of different theories came from the variety of theories taken by scientists. For them, there was no clearly correct answer and we can understand natural phenomena through different but valid perspectives" (p. 479). The following quote from a student classified as constructivist was used as evidence to support Tsai's conclusions:

> CF3: When scientists conduct experiments or make observations, their ideas are involved in their experiments and observations. Therefore, they can have quite different theories. But I think it is difficult for us to decide which one is correct and which one is wrong....Observations do not always show the exact truth or the reality. Scientists select those observations which favor their theories (p. 479).

It is not clear from this quote if student CF3 (Constructivist Female Three) sees science as accepting of multiple explanations, or if she is discussing the early stages of theory choice for a newly developed theory or explanation. An alternative explanation for Tsai's results is that students were using different contexts when discussing scientific theories. That is, one group of students may have been originally categorized as empiricist because they interpreted the questionnaire in light of confirmed theories that they believe to be absolute. Another group of students may have been categorized as constructivist because they interpreted the same questions in light of theories that have been recently proposed and have yet to be subjected to significant testing. Student CF3's comments could be considered to be consistent with either a constructivist view or empiricist view if her comments regarding theories are interpreted in light of the early stages of theory development and testing. However, CF3 gives explicit support for realist ontology and epistemology by discussing the difficulties of determining reality and of determining which theory will ultimately be "correct" and which will be "wrong." Given this quote as supporting evidence, the author's previous conclusions do not seem warranted. Further evidence to support this alternative interpretation of Tsai's results comes from the author's conclusion that, despite the fact that the constructivist students were chosen because questionnaire results indicated that they believed that scientific knowledge was constructed, it was concluded from the interview data that, "most of the students, either knowledge constructivists or empiricists, believe that science was discovered, not invented by people" (Tsai, 1998, p. 476). This is consistent with Lederman and O'Malley's (1990) finding that students' understanding of key terms or the context of questions may not be consistent with those of the researchers, thus causing incongruities between researchers' scoring schemes and students' espoused positions in more open-ended interviews.

Leach et al. (1997) summarized the research involving the development of students' understanding of the nature of science by stating that, "the picture that is emerging suggests that older students are better able to assess the implications of particular pieces of data for theories than younger students, though the nature and mechanism of age-related change is still controversial" (p. 149). To investigate this claim they engaged 30 pairs of students aged 9, 12, and 16 in science-related tasks and then asked them questions to get them to "elaborate on their actions and responses to questions in the context of the activity" (Leach et al. 1997, p. 150). Results of their study indicated that there was a significant age-related trend regarding the domain of science, with older students more likely than younger ones to classify a question as scientific on the basis that some empirical testing might be involved. With respect to experimentation and empirical testing, the authors stated that some students in each age group represented experimentation as "an unproblematic process of finding out how the world was really made" (p. 153). This view of empirical testing was higher among 9 year-olds than with the older students. Older students also tended to describe empirical investigations in more sophisticated ways with a better understanding of the mechanisms of theory testing. Results also indicated that older students were more likely to relate empirical testing to the evaluation of theories and causation. "In a small number of cases, students referred explicitly to an empirical process of data collection in order to evaluate a theory" (Leach et al., 1997, p. 157).

Leach et al. (1997) classified students reasoning about the nature of science into three basic types. *Phenomenon-based reasoning*, the lowest category, was used to describe students who failed to distinguish between description and explanation, and could not separate theory from evidence. *Relation-based reasoning*, the middle category, was used to describe students who viewed explanation as the process of relating variables through correlation. These students tended to view correlation as evidence of causation. "Although theory and evidence are separated, their relationship is seen as unproblematic, with theory emerging directly from evidence" (Leach et al., 1997, p. 159). In the highest category, ***model-based reasoning***:

> Explanation is viewed as involving coherent systems of theoretical entities, some of which may be conjectural. Multiple possibilities for explanation are thus entertained. Empirical enquiry involves evaluation of theory with respect to evidence, as is acknowledged as problematic. The relationship between theory and evidence is thus problematic: one can never be certain that a theory is correct (Leach et al., 1997, p. 159).

The authors did not claim that the students used these forms of reasoning consistently, and in fact noted that since science is a multifaceted activity, it would be appropriate for individuals to use different forms of reasoning in different science contexts. Leach et al. (1997) summarized the types of reasoning used by the subjects in their study as follows:

> The nine-year-old students in the sample used phenomenon-based reasoning across a wide range of contexts, in ways that appeared inappropriate, compared to older students. We noted very few examples of model-based reasoning amongst students of any age, and such reasoning was almost wholly absent below the age of 16. By far the most common form of reasoning, in all contexts and at all ages, was relation-based reasoning. This has certain consequences. Students viewing scientific explanation as an unproblematic process of description may well have difficulties in understanding and interpreting different viewpoints (p. 160).

The literature on students' understanding of the nature of science and the nature of scientific knowledge indicates that early adolescents generally do not view creating and testing explanations for physical phenomena as being central to the purpose of science (Solomon et al., 1994). One possible explanation for this is that the representation of techno-science in western media tends not to focus on the knowledge generation and testing aspect of science (Driver et al., 1996). Early adolescents also often have difficulty distinguishing between a description of a phenomenon and an explanation for that phenomenon (Leach et al., 1997; Solomon et al., 1994), or between ideas or explanations and experiments that are designed to be tests of those ideas (Carey et al., 1989). There are also indications that early adolescents can not distinguish between a theory and evidence that supports or refutes that theory (Kuhn & Phelps, 1982; Kuhn et al., 1988). This lack of differentiation between the various aspects of science may be due to lack of development of reasoning skills in students this age (Inhelder & Piaget, 1958). Children and young adolescents also tend to view experimentation as being random and not goal centered (Carey et al., 1989; Solomon et al., 1994), yet somehow believed that experiments were direct mechanisms for determining reality, as opposed to being tests of ideas (Leach et al., 1997). Younger adolescents tended to hold traditional, absolutist views of the nature of scientific knowledge (Meichtry, 1992; Tsai, 1998). These students also have difficulty evaluating scientific theories in light of evidence. Either the students are unaware of the relationship between explanation and evidence, or they view science as the straightforward process of description, as opposed to explanation and supporting evidence (Leach et al., 1997). Solomon et al. also reported that some early adolescents showed confusion when asked questions about science and/or the nature of science and had great difficulty generating answers to questions. While the research does show some progression from early to late adolescence in many of these areas, many researchers contend that this development could be enhanced greatly through appropriate school science experiences.

Effects of Prior Science Education

Within this section references to science curriculum, unless otherwise specified, relate to the experienced curriculum as opposed to the planned curriculum. As such, this includes textbook, teacher and classroom variables, as well as variables related to the designed curriculum.

Research regarding the effect of prior science curriculum on students' understanding of the nature of science has reported mixed results. A number of studies (Aikenhead, 1979; Carey et al., 1989; Klopfer & Cooley, 1963; Yager & Wick, 1966) have reported that curriculum innovations can cause improvements to students' understanding of the nature of science. Other studies (Jungwirth, 1970; Meichtry, 1992; Roth & Roychoudhury, 1993; Trent, 1965) have reported that curriculum innovations designed to address aspects of the nature of science have had little or no effect.

Some studies involving the explicit treatment of the nature of science in the school curriculum have focused on using the historical development of scientific ideas and explanations as a means of addressing the nature of science. For example. Klopfer and Cooley (1963) reported on a curriculum initiative called the History of Science Cases for High School (HOSC). The HOSC curriculum was a series of vignettes that illustrated the nature of science through the examination of specific cases from the history of science. In a large study (2,808 subjects) involving high school physics, chemistry, and biology classes across five months of instruction, the authors determined that the HOSC caused significantly greater gains in students' understanding of science as measured by the TOUS when compared to control groups. This conclusion held across all three subject areas and included significant gains in all of the TOUS subscales as well as the overall score.

Yager and Wick (1966) investigated the effect of three different curricular emphases on students' conception of the nature of science. Conducted at the University of Iowa Laboratory School and involving three classes of grade eight students (n = 69), the study used the TOUS as a measure of students' understanding of the nature of science. The three curriculum treatments were the TL emphasis, the MRL emphasis, and the MRLI emphasis. In the TL (text and laboratory) emphasis teachers restricted the curriculum to the textbook (T) and the accompanying laboratory guide (L). In addition, there was another aspect to the TL emphasis. According to the authors:

> The teachers avoided discussion of differences of opinion, interpretations, and reports of new findings. At times the material in the textbook touched upon these facets. However, classroom discussions avoided this area. The emphasis was upon mastery of basic concepts as identified by the authors through an inquiry approach to the laboratory (Yager & Wick, 1966, p. 16).

The MRL (multireference-laboratory) emphasis involved the use of the TL materials plus a series of other resources. A deliberate effort was made to avoid using one dominant resource. With respect to the nature of science the authors indicated that the teachers in the MRL group:

> ...avoided reference to the controversy which often occurred among the men responsible for the formation of fundamental theories. Attention given only to the varying interpretations given by modern writers. No attention was given to the history involved with new discoveries and new ideas through the ages (p. 17).

Thus while the MRL group did not deal with historical interpretations and the evolution of scientifically important explanations, they did include various current interpretations of the ideas. The MRLI (multireference-laboratory and idea) emphasis involved all of the resources and teaching emphases of the MRL group, but also included "constant attention and concern for the men involved with the development of the important ideas of science. The teachers made a conscious effort to show the mechanics of how the major theories evolved" (Yager & Wick, 1966, p. 17). The same laboratory experiences were used, however, emphasis was placed on viewing the experimental results in a historical context. The results of the study indicated that, with respect to understanding the nature of science as measured by the TOUS, the MRLI emphasis was significantly superior (at the 0.01 level) to the MRL and TL emphases, and the MRL was significantly better (0.01) than the TL emphasis. Yager and Wick (1966) concluded that, based on their findings, "Teacher emphasis in the classroom is identified as an important factor in determining student outcomes" (p. 20).

Aikenhead (1979) also investigated the effect that a grade 10 science curriculum innovation had on students' understanding of the nature of science, processes of science, and the social aspects of science. The innovation, "Science: A Way of Knowing," which included a historical, evolutionary examination of some major science explanations, was taught to 11 classes of grade 10 students (10 in Canada and one in Switzerland). Students were pre- and post-tested using the Science Process Inventory (SPI) and the Test on the Social Aspects of Science (TSAS). Results of the study indicated that the curriculum innovation increased students' understanding of the nature of science and the processes of science. The study did not use a control group, thus comparisons involve only pre- and post-test results. Further analysis revealed that gains were made in many areas. Specifically, students:

> learned to distinguish between science and technology; became more familiar with many of the fundamental assumptions underlying science; became more aware of the tentativeness of scientific knowledge; generally clarified their ideas about observations, hypotheses, laws, theories, and models; believed less in the mythical five- or seven-step "scientific method"; gained insights into the nature of classification systems and the processes of scientific inquiry; understood the meaning of induction and deduction; became more aware of the human characteristics of scientists; and recognized the effect science has on society through the technological implementation of scientific knowledge (Aikenhead, 1979, p. 25).

Other research has focused more on pedagogical issues. For example, based on clinical interviews conducted before and after a three-week unit focusing on the nature of science, Carey et al. (1989) concluded that their short-term curriculum experience caused significant changes in grade seven students' understanding of the nature of scientific knowledge and inquiry. The three-week unit engaged students in a series of hands-on activities that required that students make and test hypotheses in open-ended science inquiry activities. The researchers reported that, as a result of the unit "many students clearly understood that inquiry is guided by particular ideas and questions, and that experiments were tests of ideas" (p. 527). While Carey et al. concluded that grade seven students are generally naïve realists, they also contended that explicitly addressing the nature of science in the science curriculum can begin to move students past this stage, especially the distinction between ideas and experiments.

Other research has concluded that particular curriculum innovations designed to improve students' understanding of the nature of science, are not significantly better than traditional curricula. Trent (1965), using a sample of 52 California High Schools, investigated the effect of the PSSC physics program on students' understanding of the nature of science compared to traditional physics instruction. Utilizing the TOUS to assess understanding of the nature of science, Trent (1965) sought to determine if PSSC Physics achieved one of its intended objectives, the development of students' understanding of the nature of science. The experimental group showed significantly higher scores on the TOUS. However, in order to control for academic ability and prior science understanding, Trent performed an analysis of covariance using pre-test scores on the *Otis Quick Scoring Mental Ability* and *Test on Understanding Science*. As a result of the covariance scores, Trent concluded that there was no significant difference between the two groups.

Jungwirth (1970) investigated the ability of the BSCS Biology (Yellow version) curriculum to improve students' understanding of the "nature of scientific enquiry." The study involved 908 ninth and tenth grade students from 32 schools in Israel. Based on the results of a written device constructed specifically for this study, the author concluded that the BSCS program did not result in significant gains in understanding the nature of scientific enquiry when compared to the traditional curriculum. One important feature of this study was that it was predominantly interested in the nature of scientific enquiry and the development of science process skills. Thus the study was only peripherally involved with the nature of science. In explaining the results, the author indicated that most of the activities in the BSCS—Yellow program were more guided enquiry than true enquiry, and thus students received minimal exposure to true enquiry. This is a significant point in that guided activities are intended to have students reach a preordained conclusion. According to Hodson (1999), this requires that teachers define topics of discussion and manipulate classroom discourse in order to validate certain views. As a result, students involved in guided discovery activities do not engage in examining the validity or reliability of the experiments in which they are engaged. The students also tend not to be encouraged to offer alternative explanations or ask questions that would detract from the teachers' line of reasoning. Jungwirth did not make this specific argument in reporting the study, however, the explanation that the text was more guided enquiry than enquiry was offered in response to results that the author categorized as, "unsatisfactory achievement."

Meichtry (1992) also investigated the effect of a science curriculum innovation that related to the nature of science. She used the Modified Nature of Scientific

Knowledge Scale (MNSKS) previously described in a study involving roughly 1300 grade six, seven, and eight students. The author determined that a 26-week science curriculum innovation (BSCS middle school program) designed to expose students to a more valid representation of science actually caused students to move away from the currently accepted understanding of the nature of scientific knowledge. The level of significance established for the study was p = 0.01. The control group, which received a standard science curriculum, decreased significantly in their scores with respect to the creative aspect of science (p = 0.003), while the experimental group decreased with respect to the developmental (p = 0.001) and testable (p = 0.000) aspects of science. In discussing her results, Meichtry opined that simple exposure to a more valid representation of the nature of science in science curriculum may not be enough to cause significant shifts in students' epistemological positions. She also indicated that classroom observations had shown that teachers were not making explicit many of the aspects of the nature of science that were observed in use. She recommended that the following factors be present "to help assure that student views about the nature of science are more consistent with the scientifically accepted views":

> (1)There must be explicit representations of all aspects of the nature of science by the curriculum content taught and instructional methodology used by teachers.
> (2) The content students are learning and the processes they are using must be directly related to the various dimensions of the nature of science by the curriculum materials used by students and by the teacher. The students should not be left to make these connections by themselves.
> (3) Instructional models to induce conceptual change based on a constructivist view of learning which emphasizes the assessment of students' prior knowledge must be used. (Meichtry, 1992, p. 405)

The basis for her recommendations is not established within the study, other than to assert that those conditions present in the study were not sufficient to achieve the desired outcomes.

Roth and Roychoudhury's (1993) research with high school physics students at an all-male private school from central Canada attempted to examine the effects of interaction between the epistemological ecology established by the teacher and the epistemological positions of individual students. Specifically, the researchers sought to determine how students with varying epistemological views coped in a science class that was based on constructivist epistemology and learning theory. Based on an examination of four students' responses to essay questions, surveys and interview questions, Roth and Roychoudhury observed that students tended to view classroom experiences through their current perspective, thus they tend to see the classroom as confirming their existing view, rather than fostering change. For example, constructivist students viewed small group discussions as beneficial because they allowed for the expression of multiple viewpoints and the achievement of consensus regarding alternative explanations. Objectivist students also viewed small group work as beneficial. However, they indicated that the benefit of small group work was the elimination of errors resulting in increased probability of getting the right answer. The authors concluded that, due to this tendency to interpret the classroom in light of their existing epistemological view, "participation in a constructivist environment did not help students with an objectivist perspective of knowing to become aware of the uncertain, tentative and interpretive nature of science" (p. 43). Although Roth and Roychoudhury speculated about whether dissonance between the classroom epistemological ecology and students' individual epistemological views were related to differences in student learning, they made no comments regarding findings.

Windschitl and Andre (1998) investigated undergraduate biology students concept acquisition regarding the human cardiovascular system using various computer simulations as learning media. They found that constructivist teaching methodologies were more effective than traditional methods in causing conceptual change in two of six topics. No effect for instructional method was found for the remaining four concepts. The authors also concluded that there was a significant interaction between learners' epistemological beliefs and the epistemological stance inherent in different instructional approaches, with students with more advanced epistemological positions learning more with a constructivist treatment. Schommer's (1993) four-factor model of epistemological development was used to evaluate students' epistemological beliefs.

Research has also been conducted that investigates the role of the teacher, as opposed to the curriculum, as a factor in students' understanding of the nature of science. This research has consistently shown that teacher variables are related to students' views of the nature of science and the nature of scientific knowledge. Kleinman (1965), for example, investigated the relationship between teachers' questioning patterns and grade seven and eight students' understanding of science. The author concluded that a relationship did exist between questioning patterns and student behavior, with students of teachers who scored highly on critically thinking questions related to more engaging pupil behavior. The author did not claim that teacher questioning patterns caused changes in classroom behavior, and, in fact, noted that on some occasions "the pupil behavior appeared to be a function of ability" (p. 311). Kleinman also concluded that:

> high ability pupils in the seventh and eighth grades, who have teachers that ask critical thinking questions, have a better understanding of science, of scientists, and of the methods of science than the same caliber pupils of teachers who do not ask critical thinking questions (p. 314).

Yager (1966) also focused on the role of the teacher in developing students' conceptions of science. In trying to isolate the effect of teacher interactions from those of the curriculum, Yager investigated eighth-grade biology teachers and their classes. The teachers were similar in their academic background and were as similar as possible in their biology curriculum. “All eight teachers were involved in weekly meetings with the department head who coordinated the eighth grade course. All utilized the same number of days of discussion, the same laboratories, the same examination, and the same instructional materials” (p. 237). Students’ understanding of the nature of science was determined using pre- and post-tests of the TOUS. Yager concluded that, “Teachers demonstrate a differential ability to cause students to understand the nature of scientific enterprise and the scientists who are so engaged” (p. 241).

Lederman’s (1986) study of 18 classes of grade 10 biology students focused on identifying teaching behaviors and classroom climate variables that relate to changes in students’ conception of the nature of science. Lederman’s sample of students and teachers were administered the NSKS as a pre- and post-test before and after a one-semester biology course. It was determined that the 18 teachers involved in the study “typically possessed views consistent with those of each NSKS scale” (Lederman, 1986, p. 13). During the semester, classroom observations were made of teacher and student behavior across 44 variables. Average values were calculated for each class on each of the NSKS subscales as well as the NSKS overall for both the pre-and post-test results. The 18 classes were then evaluated based on the net change in students’ positions from the pre- to the post-test. Four teachers were identified from each extreme and the classroom variables were compared across the two groups of teachers using a binomial test (Kerlinger, 1965). Results of the analyses indicate that teachers whose classes exhibited greater change in their conception of the nature of science were typified by many behaviors. These teachers tended to be dynamic, use a variety of instructional media, be receptive to unsolicited questions, and frequently make instructional digressions. They also asked questions more frequently, asked higher level questions, asked more problem-solving questions, and probed student responses to questions. They also dealt explicitly with issues involving the nature of science in their classroom more frequently. Conversely, teachers whose classes exhibited the least positive change (and in some cases an overall negative change) were characterized by an emphasis on rote recall, extended lecturing, increased seat work, and increased down time (Lederman, 1986). The author concluded that, "the students of the 'high' classes were more attentive and exhibited more active participation. Quite simply, the classes exhibiting the largest conceptual changes were more pleasant, supportive, and on-task with students expected to think analytically about the subject matter presented" (p. 15).

Zeidler and Lederman (1989) investigated the effect of teachers' language on students' conceptions of the nature of science. The data collected in the Lederman (1986) study was used for this analysis. The 1600 pages of classroom transcripts generated during the Lederman study were analyzed and compared to the NSKS change scores previously mentioned. Zeidler and Lederman concluded that, "The results of the binomial comparisons clearly demonstrate a relationship between teachers' language and student conceptions" (p. 775). The following excerpt illustrates teacher language classified as realist versus instrumentalist with respect to the developmental aspect of science:

> Instrumentalist:
> This Big Bang Theory about the universe is believed today by most scientists. But there are still many points missing from the story. Tomorrow we may know more and this theory may be changed. Scientists admit this. They don't want to jump to

> conclusions. You can never be really sure. No matter how weird this theory sounds, most scientists believe it because in their minds it's the best model we have to explain the origin of the universe at this time.
>
> Realist:
> Student: What ratio are the hydrogens and oxygens in?
> Teacher: Two to one.
> Student: How are we supposed to know that without memorizing it?
> Teacher: You wouldn't just like you wouldn't have known what an atom is or an element is without memorizing it (Zeidler and Lederman, 1989, p. 780).

The authors also speculate on the mechanism involved in this relationship. "It appears that teachers' language reveals implicit conceptions of the nature of science which, through ordinary discourse, are subsequently conveyed to their students" (p. 775).

The Larochelle and Desautels (1991) study previously cited found that students held poorly developed views on the nature of science, especially when compared to their epistemological development in other topics/areas. However, the authors contend that the epistemological stagnation of high school students may be a function of the science curriculum, not of the students' lack of epistemological potential. They noted that students discussed school science activities as if they were observers rather than participants. Larochelle and Desautels (1991) conclude that this may be the result of the didactic atmosphere and the discourse in science classrooms. For example, use of the word "discover" has powerful implications for students' epistemology of science. According to one student, "To discover means to take out of hiding. It has always been there, you cannot discover something that was not there, for the simple reason that it would not be there at the beginning. We find something that was not there before us, but in fact, it has always been there" (Larochelle & Desautels, 1991, p. 385). The authors contend that methods of science instruction and evaluation chosen by teachers "often requires that he [the student] acts as an empiricist" (p. 387). As a result, they argue for inclusion of significant aspects of epistemology of science in the school science curriculum and the development of pedagogical strategies that will assist both teachers and students to "become familiar with the very serious game of the production of scientific knowledge" (p. 387).

Ritchie, Tobin, and Hook (1997) investigated 24 grade eight students' evaluation of their mental models during a 12-week science course (trimestered). As a result of their longitudinal ethnographic study they concluded that, while the teacher's behavior was at times consistent with constructivist pedagogical principles, and the atmosphere in the class was a pleasant and enjoyable one, the basic referent that permeated classroom discourse was the authority of the teacher and the text. The teacher's lack of chemistry background and subsequent heavy reliance on the text were identified as key aspects in this situation. As a result, the students turned to sources of authority in the evaluation of their naïve theories, rather than on the testing and refinement of their naïve concepts (Ritchie et al., 1997). While the researchers focus was on the learning theory aspect, rather than the epistemological aspect, the study concluded that teacher behavior can negatively affect students' willingness to engage in science activities that will allow them to experience the nature of science first-hand.

The literature indicates that science instruction can cause significant improvements with respect to students' understanding of the nature of science. While some research has attempted to investigate the effect of curriculum on students' conceptions, other research has focused on teacher variables. In reality, the complexity of the classroom environment minimizes the usefulness of such a simplistic dichotomy. In the end the teacher has the final say on issues of curriculum and pedagogy, thus the separation of the two is arbitrary. The work of Fullan (1991) indicates that teachers' conceptions of curriculum vary greatly and that it is the interaction of the student, the teacher and the curriculum that may make a difference, not the designed curriculum. Fullan concluded that, "Educational change depends on what teachers do and think—it is as simple and as complex as that" (Fullan, 1991, p. 117).

Issues Related to Gender

The literature indicates that significant gender differences in achievement in science are consistently reported by the end of high school level (Becker, 1989; Erickson & Erickson, 1984). Research results on gender effects below the high school level have been inconsistent, however, some general trends are discernable.

Simpson and Oliver (1990) reported the results of a 10-year longitudinal study that examined influences on adolescent students' attitude toward science and achievement in science. The study, involving students in grades six to 10 from North Carolina, investigated a broad range of variables related to home, school, and the individual. Students' attitude toward science was related to six major variables: curriculum, class climate, friends, best friend, teacher, and physical environment. Gender variables also showed some significant effects but, in general, "were not found to be as significant as expected" (p. 7). Males indicated more positive attitudes toward science and generally achieved higher in science. Females were significantly more motivated to achieve in science. While other minor differences were reported at various stages of the 10 year study, the authors concluded that, "Male and female students feel and behave toward science in much the same way" (p. 7).

Shenesh (1990) found that male students at grades seven to nine developed formal reasoning before female students and that this development was correlated to gender differences regarding interest in science. As well, Levin, Sabar, and Libman (1991) studied gender patterns in attitude and achievement of 1,934 ninth graders using Israeli data from the 1983–1984 International Association of the Evaluation of Education Achievement study. They found that gender-related differences in favor of males occurred in all four subject areas with the smallest differences apparent in biology and larger differences in earth sciences, then chemistry, and the largest differences in physics. They also reported that males scored significantly higher on questions that involved content recall, concept comprehension, and knowledge application. The least difference was reported in content knowledge questions and the greatest differences were reported in concept comprehension questions. Males also scored significantly higher on measures of scientific reasoning. However, there were no significant gender differences with respect to the nature of science.

Adamson, Foster, Roark, and Reed (1998) indicate that the science education literature shows few gender differences at the elementary level, but significant and consistent differences at the high school level. Wanting to investigate possible patterns as they emerge with younger students, the authors conducted a two-year investigation of gender variables involved in science fair projects for students in grades one to six. The science fair was an optional activity for all students. Results of the study indicated that there were no significant gender differences in participation rate, project design, merit, or awards. However, in year one of the study boys received a disproportionate number of special awards. The only consistent gender difference reported was that boys were more likely than girls to opt for physical science projects, and girls were more likely than boys to opt for biological and social science projects.

Farenga and Joyce (1999) examined gender differences in the intentions of young students to enroll in science courses in the future. The authors surveyed 427 students in grades four to six and asked them to choose courses for themselves and for members of the opposite sex. Female students chose significantly more life science courses than males, and male students chose more physical science courses than females. Overall, males chose a greater number of total science courses. When asked to select courses for a member of the opposite sex, male students chose significantly fewer courses for females than they had for themselves, while female students chose more courses for males than they had for themselves.

In general, the research results indicate that gender differences do exist with respect to science education. Research on gender effects at the elementary level is inconsistent, with few trends showing up consistently in the literature. Male and female students appear to have much in common regarding attitude toward and achievement in science at the elementary level (Adamson et al., 1998; Andre, Whigham, Hendrickson, & Chambers, 1999; Simpson & Oliver, 1990). The differences that emerge in elementary school appear to be related to subject choice, with males more likely to favor physical sciences than females (Adamson et al., 1998; Farenga & Joyce, 1999), and females either closing this gap (Adamson et al., 1998) or indicating more interest than males (Farenga & Joyce, 1999) in life sciences. However, these gender preferences are not always reflected in research results (Andre et al., 1999). Gender differences in attitude and achievement increase as students progress through the school system (Levin et al., 1991). However, few studies have investigated the role of elementary schools in these differences.

With respect to gender differences in students' understanding of the nature of science, even fewer studies have been reported. Of the articles cited previously in this chapter, only two, Jungwirth (1970) and Levin et al. (1991) made reference to an examination of gender differences in students' understanding of the nature of science. Jungwirth's study evaluated students' attainment of the intellectual skills required for understanding the nature of scientific enquiry. The study involved 908 grade nine and ten students from Israel. The author concluded that no significant gender differences were found on any of the measures used in the study. While Levin et al. found gender differences in other areas of their study of ninth grade students, they found no gender differences with respect to the nature of science.

In addition to these studies, Edmonson (1989) also investigated gender differences in students' understanding of the nature of science. Her study involved of freshman biology majors. She categorized seven of 10 male students studied as being at the objectivist end of the epistemological continuum, and only two as being at the constructivist end. Conversely, only one of 11 female subjects was classified as objectivist and five were classified as constructivist. Thus, Edmonson's research indicated that there was a gender relationship, with female biology freshman more likely to hold positions relating to the currently accepted view of the nature of science than their male counterparts.

While the research on gender differences in attitude and achievement in elementary school science is scant, there are indications that some gender patterns may be emerging. For example, some research on gender differences may indicate an epistemological parallel to the achievement research which shows gender differences appearing in late adolescence and adulthood (Edmonson, 1989).

Summary

With respect to philosophical issues, the literature indicates that there are differing views on what vision of the nature of science should be represented in the science curriculum. Many within the science education field argue for the explicit and exclusive representation of constructivist epistemology and instrumentalist ontology in the science curriculum. Many of those who argue for the exclusive portrayal of the constructivist position seem to be basing their argument on a rejection of the historical realist view of the nature of science. This view is sometimes referred to as logical positivism. Some writers argue that constructivist epistemology is post-epistemological and therefore avoids the root paradox. They contend that constructivist epistemology is a defensible philosophical position and one that maximizes student learning.

Philosophers of science have recently entered the epistemological debate in earnest. They have tended to argue the position that the current realist view is a tenable and defensible position that best represents the actual practice of science. Some philosophers of science argue for a balanced pluralistic treatment of epistemology of science. Other philosophers argue that public school students are not developmentally ready for non-realist positions, leading to the conclusion that the curriculum should reflect a naïve realist ontology. This conclusion does not imply the use of logical positivist view of the nature of science. Writers on both sides are beginning to come to agreement on the features of the nature of science that are common to both positions and that are developmentally and educationally appropriate. Both realist and constructivist writers have indicated that science involves creativity and imagination on the part of the scientist (creative factor), that scientific knowledge evolves and changes over time (developmental factor), and that science involves the generation and use of empirical evidence in evaluating theories (testable factor). This common ground is similar in many respects to the position put forward by the AAAS (1989) publication, *Science for All Americans*.

The literature regarding general epistemological positions indicates that young students are naïve realists with an absolute view of knowledge who use authority as the basis for knowledge justification. Research indicates that there is a developmental process that allows individuals to progress from this naïve realist position towards more relative ways of knowing and more contextual means of knowledge justification. Early research focussed on university students and concluded that much of this epistemological development occurs in late adolescence and adulthood. Some writers contend that this has led to the inferred position that little development occurs in children and early adolescents.

In keeping with the assumption that little epistemological development occurs in childhood and early adolescence, research on students' understanding of the nature of science has focussed primarily on high school students. This research generally concluded that high school students hold poorly developed views of the nature of science. High school students have been determined to hold predominantly logical positivist views. These views are consistent with the vision of the nature of science typically portrayed in secondary science education classrooms. Early research on the effect of science curriculum on students' understanding of the nature of science showed inconsistent results, with many studies concluding that curriculum did not significantly effect students' views of the nature of science. Some researchers opined that the lack of development in high school students' views of the nature of science was related to ineffective or inappropriate teaching and learning environments in science classrooms, not student developmental factors. Subsequent research examined factors related to students' understanding of the nature of science from a broader perspective on teaching and learning. When students' views of the nature of science were investigated in the context of the student-teacher-curriculum interaction, results consistently indicated that it was possible to change high school students' views of the nature of science. Specifically. teachers' language, the learning environment, and questioning practices of teachers have all been linked to changes in high school students' understanding of the nature of science.

For children and young adolescents the literature is sparse. The research indicates that young students are naïve realists who fail to see the knowledge-seeking nature of science, fail to distinguish between description of a phenomenon and an explanation for the phenomenon, do not view experiments as being tests of ideas, have difficulty determining if evidence supports or refutes an explanation, and generally have a difficult time discussing issues related to the nature of science. These results have led some researchers to suggest that elementary school students are not capable of holding sophisticated views of the nature of science. However, as was the case with high school students, the lack of development displayed by elementary students may be a function of the type of teaching and learning that occurs in science at the elementary level. The current research attempts to examine the issue of elementary school students' views of the nature of science by investigating the range of views held by grade six students, including those who have been exposed to differing science education experiences. This research is thus an elementary parallel of previous high school research indicating that science curriculum can affect students' understanding of the nature of science when curriculum is defined to include the interaction of the student, the teacher, and the curriculum.

While research involving gender issues in science education has shown little differences in male and female students' below the secondary level, differences have consistently been shown at high school. Research relating specifically to gender differences in students' views of the nature of science is very sparse, however, one study exists that indicates latent gender differences with respect to students' understanding of the nature of science. As a result, this study will attempt to examine possible gender differences in grade six students' views of the nature of science.

CHAPTER 3

RESEARCH DESIGN AND PROCEDURES

This study investigated eight grade six students' understanding of the nature of science, the effects that prior science curriculum may play in determining those epistemological positions, and whether gender is related to students' views of the nature of science. In selecting these students a Likert-style survey was administered to grade six students to identify their views of the nature of science. The survey was based on a three-factor model that identified scientific knowledge as creative, developmental, and testable. Those students who scored at the extremes of the continuum were selected to participate in semi-structured interviews designed to investigate and describe more deeply their understanding of key aspects of the nature of science.

Methodological Considerations

The literature review indicated that different methods of data collection have been used in the examination of students' understanding of the nature of science.

Most of the early studies that investigated students' understanding of the nature of science used questionnaires and surveys as the sole or primary data collection instrument (Lederman, 1992). For example, Wilson (1954) used the Science Attitude Questionnaire (SAQ) in his study of Georgia high school students. Klopfer and Cooley (1961) developed the Test of Understanding Science (TOUS), a multiple-choice criterion-referenced test that addressed several aspects of the nature of science and the scientific enterprise. Several of the studies previously reported have used the TOUS for all or part of the data collection (Mackay, 1971; Miller, 1963; Trent, 1965; Yager, 1966; Yager & Wick, 1966). Kleinman (1965) also developed the TOUS-Jy, an adaptation of the TOUS, for use with junior high school students. Teachers involved in the Kleinman study reported that low-ability students experienced reading difficulties with the instrument. The study therefore omitted the low-ability group students from the statistical analysis of the data (Kleinman, 1965).

The NSKS, a five-point Likert-style questionnaire, was developed and used by Rubba and Anderson (1978) to evaluate high school students' understanding of the nature of scientific knowledge. The NSKS has been used in several other studies (Lederman, 1986; Lederman & Druger, 1985; Zeidler & Lederman, 1989). Meichtry (1992) also developed the MNSKS, an adaptation of the NSKS, for use with students in grades six to eight. No difficulties were reported with respect to the use of this instrument.

In some cases researchers have also developed their own survey instruments to evaluate students' understanding of the nature of science and the nature of scientific knowledge (Jungwirth, 1970; Lederman & O'Malley, 1990).

Starting in the late 1980s, however, the exclusive use of pencil and paper survey instruments for investigating students' understanding of the nature of science began to receive some criticism in the literature (Aikenhead, 1987; Carey et al., 1989; Lederman & O'Malley, 1990). These criticisms revolved around "the potential pitfall of assuming that students perceive the same meaning in an item as the researcher" (Aikenhead, 1987, p. 484).

In response to these concerns, Lederman and O'Malley (1990) conducted a study to evaluate the use of pencil and paper questionnaires versus interviews in investigating students' understanding of the tentativeness of scientific knowledge. For their study a questionnaire consisting of a series of open-ended questions was developed. The instrument was used as a means of data collection and was also used as a mechanism of identifying students for possible inclusion in subsequent interviews. Based on the survey results the students were classified into a dichotomy based on whether they held absolutist or tentative views of science. The dichotomies were established based on the work of Cotham and Smith (1981). The results of the interview portion of the study were then compared with the questionnaire results. Lederman and O'Malley determined that the interview results did not confirm the conclusions drawn from the questionnaires, and that most of this misinterpretation related to researchers' assumptions about students' use of the term "prove" in science. All of the students interviewed were determined to hold views consistent with a tentative perspective, even those who had been classified as absolutist on the basis of the questionnaire results. The authors stated that:

> the use of the interviews to gather and clarify data about students' beliefs appears to be essential if one is to avoid the pitfalls of misinterpretation. The implications of this finding for the results of over three decades of research concerned with students' and teachers' beliefs about science (virtually none of which included interviews) is clearly disconcerting at best (Lederman & O'Malley, 1990, p. 235).

Lederman and O'Malley indicate that combining questionnaires with interviews provides a basis for determining if researchers assumptions about the meaning of students' questionnaire results are accurate.

Similarly, Carey et al. (1989) argued that pencil and paper forms of data collection "have a clear limitation: multiple-choice and scaled response assessment measures necessarily place constraints on what can be revealed of students' own initial conceptions. Further, it is not possible to know what students understand about the terminology used during the test" (p. 519-520). Roach (1994) also concluded that Likert-style questionnaires are useful for investigating students' understanding of the nature of science and the nature of scientific knowledge. She, like the others, concluded that the limitations of questionnaires suggest that they should not be the sole data collection method used for the study of epistemology of science or for comparing the epistemological stances of two groups. In her study she combined questionnaire results with content analysis of journals, as well as conducting interviews. She argued that interviews should accompany methods such as Likert-style questionnaires when investigating students understanding of the nature of science and stressed the need for the use of multiple data sources for increasing validity in such research.

The advantages of Likert-style questionnaires are that they are quick to administer, straightforward, and the results can be easily used for quantitative data analysis. The disadvantages of Likert-style questionnaires are that the vocabulary and reading level of students can affect the results, they do not allow students the opportunity to express their understanding in their own terms, and they can be subject to misinterpretation unless verified against other forms of data collection.

Recent research investigating students' understanding of the nature of science has used questionnaires as one of multiple methods in studies to determine students' views of the nature of science (Roth & Roychoudhury, 1993, 1994; Roach, 1994; Solomon and Scott, 1994; Songer & Linn, 1991; Tsai, 1998)

Tsai (1998) defined two views of the nature of scientific knowledge, empiricist and constructivist. According to Tsai:

> The empiricist views about science tend to support that: (1) scientific knowledge is unproblematic and it provides *right* answers; (2) scientific knowledge is *discovered* by the *objective* data gathered from observation and experimenting or from an universal scientific method; (3) scientific knowledge is additive and bottom-up, and evidence carefully accumulated will result in infallible knowledge (p. 474–475).

Tsai also indicated that, "the constructivist views assert that scientific knowledge is constructed (or invented) by scientists, its status is tentative, and its development experiences a series of revolutions or paradigm shifts" (p. 475). The author used the results of the Science Epistemological Beliefs (SEB) questionnaire to differentiate between students who held empiricist versus constructivist views of scientific knowledge. Students representing the extreme positions were chosen to participate in subsequent interviews to determine the range of epistemological beliefs with respect to science.

Over the last decade interviews have been the predominant methodology used in reported studies examining students' understanding of the nature of science. Most of the interviews have been semi-structured in nature. That is, topics pertinent to the study have been identified, initial questions or probes to open up the dialogue in those areas have been determined, and the subjects are then engaged in follow-up questions designed to clarify the individuals' position. In some cases (Ryder, Leach, & Driver, 1999; Solomon et al., 1994) multiple interviews over an extended time frame have been used to investigate longitudinal effects.

The use of ethnographic methodologies in this area has been quite limited. The study by Ritchie et al. (1997) used an ethnographic design. However, the primary purpose of this study was to examine the interaction between the teacher and students, rather than investigating students' views of the nature of science.

Several researchers have commented on the broad view of science which students hold. (Aikenhead, 1987; Driver et al., 1996; Fleming, 1987). According to Driver et al. (1996):

> Science covers a tremendous range of activities (from routine laboratory testing to multi-million pound particle physics); technology (which students may not distinguish clearly from science) broadens the scope further. There is, therefore, a very wide range of contexts and examples which individuals may call to mind in responding to any one question about the purpose of scientific work. So questions about the purpose of science beg the questions: 'what purpose?' and 'which science?' (p. 48).

Aikenhead, Flemming, and Ryan (1987) use the term "technoscience" to refer to this broad conception of science and technology. In response to the methodological implications of this broad view of science, some researchers argue against using ethnographic techniques to investigate students' views of the nature of science. Driver et al. (1996) contend that:

> one might, for instance, observe children in normal science classes and ask them about what they thought they were doing and why. Only some class activities, however, would raise issues of interest, and even coverage of the range of issues and questions would be difficult to achieve. Also, variations of context and setting would be considerable, the researcher imposing almost no constraints on the situations observed. There is also a further limitation to such an approach, in that activities conducted in science lessons may provide little potential for addressing the work of practicing scientists; school science is conducted for different purposes than 'real science' and students may recognize this (p. 66).

Driver et al. argue that a more consistent and realistic setting would place the student in a context where the images and purposes of science would be deliberately limited to the range that was to be addressed in the research. While there is no guarantee that students will not misinterpret the context, the likelihood that the student will interpret the context in similar ways will be greatly enhanced. Leach et al. (1997) concluded that the most productive approach may be in:

> designing tasks to be completed by young people, and then asking them to elaborate upon their actions and responses to questions in the context of the activity. The advantage to this approach is that the researchers can select appropriate contexts for their interests, rather than waiting for these to arise in the classroom (p. 150).

This use of a "scenario" places the students in a situation where issues of relevance to the study will occur, provides a constant context, and still allows researchers to ask questions and probe students' answers. As a result, the students' responses are less open to misinterpretation since the student can discuss them in the context of the scenario.

This study uses both a Likert-style questionnaire and a semi-structured interview written around a specific context to investigate students' understanding of the nature of science.

Sample

The primary focus of the study was to identify and describe the range of positions that grade six students held with respect to the nature of science. Secondary research questions dealt with the effects that gender and prior exposure to science curriculum may have on students' views in this area.

Two schools were selected to participate in the study. School A was a rural elementary school (K-6) of approximately 200 students and an extensive elementary science curriculum program (Nova Scotia Department of Education and Culture [NSDEC], 1995; Schoenberger, 1995). It was chosen for this study because of its involvement in a long-term elementary science curriculum initiative. The implementation of this curriculum project lasted seven years (1989-1996) and involved teachers and schools in extensive professional development activities in the area of elementary science education (NSDEC, 1995). A university-based, elementary science education professor facilitated the professional development activities (Schoenberger, 1995). The student population at School A had little turnover during the curriculum project, with the majority of students having attended the school for their entire schooling. None of the interviews with students from School A involved students who were recent transfers, assuring that the students chosen had significant exposure to the curriculum initiative (H. Dill, personal communication, March, 1996).

The science curriculum at School A was based on the *Science: A Process Approach* (SAPA) and *Elementary Science Study* (ESS) programs. The primary focus of this curriculum was the development of students' science process skills and the subsequent use of these skills in the construction of "best explanations" for physical phenomena. These activities were structured to build on students' prior knowledge as they asked questions about the nature of a broad range of science-related topics through a series of open-ended, hands-on, learning experiences designed to engage students in generating and answering science-related questions. Students were exposed to, and participated in, a series of investigations involving life, physical, earth, and space science (NSDEC, 1995; Schoenberger, 1995). The elementary science project was viewed by Department of Education personnel as a model of curriculum implementation because of the high level of on-going professional development in support of the implementation science (NSDEC, 1995; Schoenberger, 1995). Thus School A was different from schools not involved in the project by virtue of the emphasis on elementary science, the open-ended constructivist approach of the curriculum, and the extent of professional development opportunities designed to allow teachers to effectively implement the curriculum as designed.

Students were routinely involved in the process of creating, testing, and evaluating their own explanations for real-world phenomena through hands-on activities in science. This often involved justifying their explanations based on the data and evidence at hand (NSDEC, 1995; Schoenberger, 1995). However, additional issues involving criteria for scientific decision making were not directly addressed in the curriculum at School A (NSDEC, 1995; Schoenberger, 1995). At School A, manipulative materials for mathematics and science were conspicuous in classrooms and were often in use.

School B was also a rural elementary school of approximately 300 students (K–6) located in the same school district as School A and with class sizes similar to School A. School B had not been involved in the elementary science curriculum initiative. While teacher in-service opportunities were available to School B. they were not as extensive as School A and did not focus on science curriculum. Based on interviews and discussions with personnel from the Department of Education and Culture, the school board. the school principal, and the grade six teacher involved, it was determined that students in School B were significantly less involved with hands-on science activities. Typical science learning experiences included reading about science and some demonstrations. Math and science manipulatives were not readily observable in School B. Thus, School B was a matched school that was selected based on its similarity to School A in all other aspects except for science curriculum (B. Corbin, personal communication, September, 1995; K. Rosborough, personal communication, September, 1995).

Volunteers from each grade six class were administered a survey instrument that was designed to identify students' epistemological positions. Based on the survey results, students were scored on the extent to which their understanding of the nature of science reflected the creative, developmental, and testable model of the nature of science previously mentioned. High scores indicated those students in the sample whose understanding of the nature of science and the nature of scientific knowledge most reflected the model. Low survey scores indicated those students in the sample least representative of the three-factor model.

Four students from the sample were selected to represent the higher end of the continuum. The students chosen were the highest male and female survey score from each of the two classes. Likewise, the lowest male and lowest female scores from each class were chosen to represent the lower end of the continuum.

This method of subject selection was chosen because it guaranteed that subjects in the interviews would be representative of both schools, both genders, and both extremes of the NSKSE, thus allowing a broad range of positions to be investigated. Since this method of subject selection also maintained a subject balance between the two schools, it allowed an examination of the effect of prior science curriculum on students' understanding of the nature of science. Because the selection also maintained a gender balance, an examination of possible gender effects on students' views of the nature of science was possible. An alternative method of sample selection would have been to simply choose the four highest and four lowest scores on the NSKSE regardless of gender or school. While this could result in more polar groups it would not guarantee the school and gender balances required for the examination of the possible effects of prior science experience and gender on students' epistemological positions.

Instruments

The Nature of Scientific Knowledge Scale—Elementary (NSKSE)

The Nature of Scientific Knowledge Scale—Elementary was developed by the researcher for the purposes of this study. It is an adaptation of the Nature of Scientific Knowledge Scale (NSKS) created by Rubba and Anderson (1978) and the Modified Nature of Scientific Knowledge Scale (MNSKS) developed by Meichtry (1992). The original instrument was developed to assess secondary school students' understanding of the nature of scientific knowledge (Rubba & Anderson, 1978).

Rubba and Anderson began by establishing a model of the nature of scientific knowledge. Based on a review and analysis of the literature, they developed a six-factor model that characterized scientific knowledge as amoral, creative, developmental, parsimonious, testable, and unified. This model was then submitted to three philosophers of science who were asked to independently review and critique the model in light of the following questions:

1. Does the model reflect the prominent features of scientific knowledge as they are generally held among philosophers of science and practicing scientists?
2. Does the model constitute an inclusive model of the nature of scientific knowledge?
3. Are the model factors exclusive?

Following a review and revisions, the six-factor model was endorsed by all three philosophers of science as a valid representation of the current publicly held understanding of nature of scientific knowledge. The six factors are summarized from

Rubba and Anderson (1978):

> AMORAL
> Scientific knowledge provides man with many capabilities, but does not instruct man on how to use them. Moral judgements can be passed only on man's application of scientific knowledge, not on the knowledge itself.
>
> CREATIVE
> Scientific knowledge is a product of the human intellect. Its invention requires as much creative imagination as does the work of an artist, a poet, or a composer. Scientific knowledge embodies the creative essence of the scientific inquiry process.
>
> DEVELOPMENTAL
> Scientific knowledge is never "proven" is the absolute and final sense. It changes over time. The justification process limits scientific knowledge as probable. Beliefs which appear to be good ones at one time may be appraised differently when more evidence is at hand. Previously accepted beliefs should be judged in their historical context.
>
> PARSIMONIOUS
> Scientific knowledge tends toward simplicity, but not at the disdain of complexity. It is comprehensive as opposed to specific. There is a continuous effort to develop a minimum number of concepts to explain the greatest number of possible observations.
>
> TESTABLE
> Scientific knowledge is capable of public empirical tests. Its validity is established through repeated testing against accepted observations. Consistency among test results is a necessary, but not a sufficient condition for the validity of scientific knowledge.
>
> UNIFIED
> Scientific knowledge is born out of an effort to understand the unity of nature. The knowledge produced by the various specialized sciences contribute to a network of laws, theories, and concepts. This systemized body gives science its explanatory and predictive power (p. 456).

In accordance with Rubba and Anderson's (1978) view that each factor in the model represents a continuum along which students can proceed, they determined that a Likert-style survey would be the most appropriate type of instrument to develop. Therefore, following the validation of the six-factor model a pool of statements was generated for each of the factors. Each item was examined for clarity and reading level by the authors and then, based on a field-test of items for reading level with grade nine students, revisions were made. The surviving items were given to a panel of science education doctoral students to evaluate for form and content. The resulting item statements were attached to a five-point Likert scale and piloted with a group of junior high school students. Based on the pilot, revisions and deletions were again made resulting in a pool of 114 surviving item statements.

The pool of 114 statements was submitted to a panel of nine experts for evaluation of content validity. The panel consisted of two philosophers of science, two science educators, two scientists, two experienced high school science teachers, and one psychometrician. After two rounds of item statement judging and revision. 36 positive and 36 negative items were judged by the panel members as representing the previously validated six-factor model.

Following this the 72 item statements were field tested with 674 high school students and the 48 most discriminating-reliable combination of items were selected for inclusion in the instrument.

Each of the six subscales of the NSKS consisted of eight Likert-style questions with a five-point scale. Four of the statements were written in the positive mode and four were written in the negative mode. For scoring purposes the "negative" mode questions were reversed. Thus the lowest possible score on each subscale was eight and the lowest possible total score on the NSKS was 48. These scores represented a perspective in complete disagreement with the model developed. The highest possible score on each subscale was 40 and the highest possible total score on the NSKS was 240. These scores represent a perspective in complete agreement with the model developed.

Rubba and Anderson (1978) evaluated the reliability of the NSKS in two ways.

Test-retest reliability was established with two groups of high school students. The two samples used were grade nine general science students (n = 52) and grade 12 advanced chemistry students (n = 35). The time span between the two tests was six weeks. The Pearson product-moment test-retest correlations were r = 0.59 and r = 0.87 for the grade nine and 12 students respectively. Internal consistency of the NSKS was determined by administering the device to samples of secondary school and university students and subsequent calculation of Cronbach's alpha for each group. A brief description of the samples and the resulting coefficient alphas are listed in Table 2.

Table 2

NSKS Coefficient alpha reliability functions (Rubba & Anderson. 1978)

Sample	Number	r_{kk}
Grade 9 General Science Students	101	0.65
Grade 9/10 Biology Students	311	0.74
Grade 11/12 Chemistry Students	111	0.74
Grade 11/12 Physics Students	36	0.77
Grade 12 Advanced Chemistry Students	36	0.89
College Freshman (non-science majors)	194	0.80
College Freshman (philosophy of science students)	160	0.88

As evidenced by the results in Table 2, there is a general trend toward greater internal reliability on the NSKS as the students' education level increases. This trend could be related to age or some other factor such as previous science courses.

Lederman and Druger (1985) also calculated coefficient alphas for the NSKS results from their study involving 18 grade 10 biology classes and their teachers. Coefficient alphas for the subscales ranged from 0.66 to 0.77 on the pre-test for the students and from 0.70 to 0.87 for the teachers. Coefficient alphas for the NSKS overall on the pre-test were 0.77 for the students and 0.93 for the teachers.

Panels of experts had previously established the content validity of the six-factor model and the NSKS item statements. Construct validity of the NSKS instrument was examined using an *ex post facto* research design. Two groups of college freshman were involved in the sample. One sample consisted of freshman completing a introductory college philosophy of science course and the other consisted of freshman at the same college who were completing a biology course for non-science majors. The philosophy of science students scored significantly higher on the developmental, parsimonious, testable, and unified subscales, as well as on the combined NSKS score. No significant differences were found to exist between the two groups on the variables of gender, age, number of high school science courses taken, and semester hours of college science completed (Rubba & Anderson, 1978). These findings are evidence of the validity of the NSKS as a measure of college students' understanding of the nature of scientific knowledge.

The NSKS was originally designed for use with students in grades nine to twelve. Meichtry (1992) revised the NSKS for use with students in grade six to eight. Her device, the Modified Nature of Scientific Knowledge Scale (MNSKS), differed from the NSKS in two ways. First, she omitted the parsimonious and amoral subscales from the instrument. Second, she edited the remaining statements for the reading level of the students involved (grades six to eight). While Meichtry did not indicate the reasons for the two deleted subscales, a valid argument can be made for their exclusion. In the case of the amoral subscale, the publicly accepted view of the nature of science had changed since Rubba and Anderson's work in 1978. The current publicly accepted view of the nature of science would not support Rubba and Anderson's description of science as being morally neutral (AAAS, 1989, 1993; Alberta Education, 1990; CMEC, 1997;

Nadeau & Desautels, 1984; NRC, 1996). Thus the decision to omit the amoral subscale can be defended on the basis that it no longer reflected our current understanding of the nature of science.

While the notion of parsimony still figures prominently in current descriptions of the nature of scientific knowledge (AAAS, 1989; Aikenhead, 1991; Field, 1985; Giere, 1991), it is a relatively complex concept and is not commonly dealt with in junior high school science education. Since Meichtry's subjects spanned grades six to eight, the concept of parsimony would not likely have been a useful one for measuring the epistemological stances of these students. While parsimony is important in science, it is an abstract concept with which students are generally not familiar. As well, parsimony is typically not dealt with in the science curriculum until high school, if at all. For example, the current Nova Scotia and Saskatchewan science curricula' deal with the topic at the grade 10 level. Neither the term, nor the concept of parsimony is mentioned in the major national publications *National Science Education Standards* (NRC, 1996), the *Scope Sequence, and Coordination of Secondary School Science, (Volume III): A High School Framework for National Science Education Standards* (NSTA, 1995), or *Benchmarks for Scientific Literacy* (AAAS, 1993).

The MNSKS item statements, once developed, were evaluated for content validity by a panel of four university science educators (Meichtry, 1992). The panel verified that the MNSKS reflected a valid understanding of the nature of scientific knowledge at that time. This is a significant point for the current research, since it supports the position that the creative, developmental, testable, and unified factors and their item statements were still considered to accurately reflect the commonly held understanding of the nature of science at the time of publication. Meichtry also evaluated the internal consistency of the MNSKS by calculating Cronbach's alphas for the pretest data received from the 1300 grade six, seven, and eight students in her study. The resultant coefficient alphas were: Creative Subscale (0.55); Developmental Subscale (0.46); Testable Subscale (0.45); Unified Subscale (0.60); and the MNSKS overall score was (0.77). These values were deemed by the author to be acceptable for the purposes of the study.

Given that the MNSKS had been evaluated for both validity and reliability, it was taken as the starting point for the development of the Nature of Scientific Knowledge Scale—Elementary (NSKSE). However, an analysis of current elementary science curriculum documents and supporting material performed by the researcher indicated that grade six students should have learning experiences that expose them to features of science that relate to only three of Meichtry's four factors (APEF, 1998; AAAS, 1993, 1993; CMEC, 1997; NRC, 1996), the creative, developmental, and testable factors.

Since the NSKS and the MNSKS were both determined to be valid, and the NSKSE is representative of the both of these instruments, the validity of the previous instruments should be applicable to the NSKSE. Further evidence of content validity of the creative, developmental, and testable subscales can be found in the recent literature. Matthews (1998), Staver (1998), and Abd-El-Khalick et al. (1998) all describe features that they argue are valid aspects of the nature of science and that both constructivists and realists could agree were pedagogically appropriate for students. Abd-El-Khalick et al. (1998) identified the following attributes:

> Scientific knowledge is tentative [developmental]...; empirically based [testable]...; subjective...; partly the product of human inference, imagination, and creativity [creative]...; and socially and culturally imbedded. Two additional important aspects are the distinction between observations and inferences, and the

function of, and relationships between scientific theories and laws (p. 418). The constructivist perspective that Staver (1998) argues for explicitly defines science as the creation of scientific explanations [creative]. Staver also indicates that by opting for truth as internal coherence, science gets to retain the empirical character of science [testable] that allows for decisions about theory choice and therefore evolution of explanations [developmental]. He embraces Thomas Kuhn's (1970) views of ordinary and extraordinary science as a mechanism for theory choice and development. Similarly, Matthews (1998) states that:

> Most realists are sophisticated about science and its history. They recognize that science is a human creation [creative], that it is bound by historical circumstances, that it changes over time, that its theories are underdetermined by empirical evidence [testable], that its knowledge claims are not absolute [developmental], that its methods and methodology change over time. that it necessarily deals with abstractions and idealizations, that it involves certain metaphysical positions, that its research agenda are affected by social interests and ideology, that its learning requires that children be attentive and intellectually engaged. and so on. These are positions that both sides can happily agree about and can encourage students to appreciate (p. 166).

Matthews (1998), Staver (1998), and Abd-El-Khalick et al. (1998) all either explicitly or implicitly indicate that science is creative, developmental, and testable.

A similar mapping can be completed for the major curriculum development documents that underpin scientific literacy. The Pan-Canadian Common Framework of Science Learning Outcomes (CMEC, 1997) describes science as:

> a human and social activity with unique characteristics and a long history that has involved many men and women from many societies. Science is also a way of learning about the universe based on curiosity, creativity, imagination, intuition, exploration, observation, replication of experiments, interpretation of evidence, and debate over the evidence and its interpretations. Scientific activity provides a conceptual and theoretical base that is used in predicting, interpreting, and explaining natural and human-made phenomena. Many historians, sociologists, and philosophers of science argue that there is no set procedure for conducting a scientific investigation. Rather, they see science as driven by a combination of

> theories, knowledge, experimentation, and processes anchored in the physical world. Theories of science are continually being tested, modified, and improved as new knowledge and theories supersede existing ones. Scientific debate on new observations and hypotheses that challenge accepted knowledge involves many participants with diverse backgrounds. This highly complex interplay, which has occurred throughout history, is fuelled by theoretical discussions, experimentation, social, cultural, economic, and political influences, personal biases, and the need for peer recognition and acceptance.
>
> While it is true that some of our understanding of the world is the result of revolutionary scientific developments, much of our understanding of the world results from a steady and gradual accumulation of knowledge (p. 9).

In this brief passage the authors described science as being creative, developmental, and testable. For example, they list creativity and imagination as two of the factors involved in the processes of science (creative factor). They also refer to scientific knowledge as, "continually being tested, modified, and improved as new knowledge and theories supersede existing ones" (testable and developmental factors). As well. the description of scientific debate and decision making have fairly explicit references to the developmental and testable nature of science. It is also worth noting that parts of this excerpt are in disagreement with Rubba and Anderson's amoral factor, thus supporting the decision to omit this factor from the MNSKS and the NSKSE.

More references in support of the testable factor exist in the Atlantic Canada Science Foundation Document (APEF, 1996). This document provides a framework for science curriculum development in public schools in the Atlantic Provinces. The AAAS publications *Science for All Americans* (1989) and *Benchmarks for Scientific Literacy* (1993) also support the importance of the creative, developmental, and testable factors. The creative factor is referred to explicitly in the following quote, "Inventing hypotheses or theories to imagine how the world works and then figuring out how they can be put to the test of reality is as creative as writing poetry, composing music, or designing skyscrapers" (p. 27). As well, the notion of testing scientific ideas is described as being fundamental to science. The AAAS (1989) states that, "the process of formulating and testing hypotheses is one of the core activities of scientists. To be useful, a hypothesis should suggest what evidence would support it and what evidence would refute it. A hypothesis that cannot in principle be put to the test of evidence may be interesting, but it is not scientifically useful" (p. 27). The following passage, which addresses the developmental nature of scientific knowledge, also makes reference to the creative and testable aspects of science:

> *Scientific Ideas are Subject to Change*
> Science is a process for producing knowledge. The process depends both on making careful observations and on inventing theories for making sense out of those observations. Change in knowledge is inevitable because new observations may challenge existing theories. No matter how well one theory explains a set of observations, it is possible that another theory may fit just as well or better, or may fit a still wider range of observations. In science, the testing and improving and occasional discarding of theories, whether new or old, goes on all the time (AAAS, 1989, p. 26).

As well, Zeidler and Lederman (1989) used high scores on the creative, developmental, and testable subscales of the NSKS as an indication of high school students' epistemological positions. Zeidler and Lederman identify the view of science conveyed in the three-factor model and the item statements as a defensible and desirable view of the nature of science.

Based on the previous argument, the three-factor model of the nature of science (creative, developmental, and testable) on which the NSKSE was based was deemed by the researcher to represent a valid and age-appropriate understanding of the nature of science for grade six students. This conclusion was based on the validation processes involved in the NSKS and the MNSKS upon which it is based, and also on an analysis of the current literature.

This researcher drafted a prototype version of the NSKSE instrument. This version consisted of three subscales of eight items each. It was distributed to grade six teachers at a large semi-rural school for feedback and editing suggestions. Teacher concerns included vocabulary and the willingness of grade six students to remain engaged for the length of time required to complete the survey. Based on this feedback one positive and one negative item statement from each factor was deleted. The items chosen for deletion were those which, in the opinion of the teachers, presented the greatest vocabulary and reading level challenge to the students. The only other change was a minor language edit.

The resultant three-factor, 18-item instrument was distributed to one class of grade six students at the pilot school, following which students and teachers were asked for feedback and suggestions. Based on this feedback some minor grammatical revisions were made.

The resultant NSKSE is shown in Appendix 1. The subscale associated with each statement and an indication of whether it is a positive or negative statement is included in brackets for the purposes of this summary. The scoring sheet used by students is shown in Appendix 2. To evaluate the internal reliability of the NSKSE Cronbach's alpha was calculated for the data collected from the pilot study (n=20). The reliability coefficients received were as follows: Creative Subscale (0.55); Developmental Subscale (0.78); Testable Subscale (0.64); and the NSKSE total was (0.62). These were deemed to be within acceptable range for the purposes of this study (Mehrens & Lehmann, 1984).

Interview Protocol

The interview protocol was developed in the context of an investigative science activity. The use of a meaningful context has several advantages. One such advantage is that it provides the same starting point for all students. Previous research (Driver et al., 1996) indicates that students' images of science are very broad and are based on a wide range of media, school science, and real-life representations of science inquiry, technology, and medicine. This broad, composite view of science is sometimes referred to as technoscience (Aikenhead et al., 1987). This issue has implications for this study because an open-ended, decontextualized initial question such as, "What is a theory?" may cause students to relate the word "theory" to many different contexts. some of which may not be scientific. Thus, opening the interview in the manner chosen allowed students to use and discuss the term theory in a scientific context. While engaging students in a dialogue about the term theory may have resulted in some interesting discussion and insights about students' conceptions of the term, those discussions may or may not have been related to the issues addressed in this research.

A second benefit of the context was that it served as a reference point for future aspects of the protocol. This is the case for both specific issues related to properties of oil and also for more general issues such as the nature of scientific knowledge. Thus the contextual opening laid the groundwork for subsequent topics. For example, in the opening section of the protocol students were read a description of a theory that explained properties of oils. They were then asked whether or not they believed the theory and why they did or did not believe it. Later questions dealt with the nature of theories in general, the nature of supporting evidence in general, and evaluating data to determine if they supported the theory.

The context selected for this interview was an investigative activity typical of grade six school science experiences. In this scenario a student, Amanda, postulates a theory that deals with some properties of oils. A third benefit of the use of this context was that the properties of oil being discussed could be understood and explained by grade six students. Based on the responses from the pilot study, grade six students could create and evaluate models that could account for the properties of oil in question. Further, the students could generate their own data that could be used to evaluate the theory. Based on the Pan-Canadian Common Framework of Science Learning Outcomes (CMEC, 1997), grade six students should possess the science process skills necessary to conduct such an investigation as well as the ability to evaluate data to determine if it was confirming or disconfirming of a particular theory. Based on the literature and the responses of the pilot students to this activity, the investigations and the associated questions were deemed to be developmentally appropriate for students of this age and grade level.

The use of the scenario also allowed an additional feature to be included in the study. Students were asked first to discuss and describe their understanding of the role of supporting evidence in evaluating scientific theories. Then they were placed in a situation where they evaluated Amanda's theory on the basis of data that they had generated. This sequence allowed an examination of the students' epistemology in action and subsequent comparisons to their espoused epistemology.

One disadvantage of this methodology is that it provided students with an example of a theory early in the protocol. This could allow the subjects to use the example, or things that they learned from the example, in their own explanations.

Likewise, the existence of the example may limit students from developing their own examples that more fully illuminate their understanding of certain topics. However, given that the primary focus of the research was investigating students' understanding of the nature of science, it was decided that the strengths and opportunities afforded by using this context outweighed the negative aspects.

The interview protocol was developed and subsequently piloted with two male and two female students chosen from the grade six pilot group. Based on feedback from the pilot some minor modifications were made to the wording and sequence of the questions.

Given that the interview was intended to investigate grade six students' understanding of the nature of science, it should also be possible to relate the interview questions to the three-factor model. This mapping is shown in Appendix 3.

Summary

This chapter described the procedures used for subject selection in the study and also outlined the development of the NSKSE Likert-style questionnaire and the interview protocol used. The subject selection procedure permitted an investigation of the primary focus of this research, to identify and describe the range of positions that grade six students' held with respect to the nature of science and the nature of scientific knowledge. It also permitted an investigation of differences related to gender and to prior science curriculum on students' epistemological positions.

CHAPTER 4

RESULTS

Introduction

This chapter reports the results of a survey, the Nature of Scientific Knowledge Scale—Elementary (NSKSE), and describes selected students' understanding of the nature of science as determined from semi-structured interviews.

A Likert-style questionnaire, the NSKSE was designed to measure students' understanding of the nature of science and the nature of scientific knowledge. The NSKSE is an adaptation of the NSKS (Rubba & Anderson, 1978) and the MNSKS developed by Meichtry (1992). The NSKSE is a subset of the MNSKS, modified in length and reading level to suit grade six students, and is based on a three-factor model that defines scientific knowledge as creative, developmental, and testable. Therefore, the NSKSE consists of three subscales plus a total score. Each subscale (factor) consists of six item statements on a five-point Likert scale (1–5). High scores indicate student positions in agreement with the three-factor model and were taken to represent a position consistent with the current understanding of the nature of science. Possible scores for each subscale ranged from a low of six (strong disagreement with the model) to a high of 30 (strong agreement with the model) and the possible total score ranged from 18 to 90. The midpoints for the instrument are 18 for each of the subscales and 54 for the full NSKSE.

The NSKSE was administered to grade six classes from two schools. The schools are both small, rural, elementary (K–6) schools within the same school district in Atlantic Canada. School A was chosen for this study because it was involved in a long term (1988–1995) elementary science curriculum initiative. School B was chosen because, in the opinion of school board and Department of Education personnel, it matched School A for size, demographics, and socioeconomic status but was not involved in the elementary science curriculum initiative. While the science curriculum in School A was characterized as hands-on, activity oriented, and involving generating and testing explanations for real-world phenomena, the curriculum at School B was characterized as giving minimal treatment to science, not involving students in constructing and testing explanations for physical phenomena, and involving few activities.

Based on the results of the NSKSE, four students from each school were chosen to participate in semi-structured interviews designed to further investigate students' understanding of the nature of science. The students chosen were the highest and lowest scoring male and female from each class. These students were chosen because they had the potential to provide a range of student positions, while still allowing a gender balance and equal representation from both schools. This allowed the study to examine possible gender differences as well as possible differences based on prior science curriculum.

Results of the NSKSE

A total of 38 students participated on this study, 17 from School A and 21 from School B. Subscale scores for the combined group ranged from a low of 13 to a high of

30, with a mean of 21.6. NSKSE results ranged from a low score of 55 to a high score of 79, with a mean of 64.8.

Midpoint scores on the NSKSE and each of the subscales were 54 and 18, respectively. The results of this study showed that the combined group of students had mean scores on each subscale and on the NSKSE which exceeded the midpoint, thus indicating that the students' survey scores were generally consistent with the three-factor model of the nature of science used in the design of the instrument. Of the 114 subscale scores (38 students times three subscales each), 106 (93%) were at or above the midpoint and all 38 students scored above the midpoint on the NSKSE overall (n = 38, see Table 3).

Table 3

Percentage of Students Scoring at or Above the Midpoint on NSKSE and Subscales

Scale	% below midpoint	% at or above midpoint
Creative Subscale	11%	89%
Developmental Subscale	3%	97%
Testable Subscale	8%	92%
NSKSE	0%	100%

The results of the NSKSE indicate that the grade six students surveyed generally agree that science is a creative, developmental, and testable endeavor. However, the range of scores indicates that the level of support for this position varies greatly.

Gender Effects

In this study no significant differences were found between males and females on any of the subscales or on the NSKSE. This held for each school individually, as well as for the combined data. Tables 4–6 report the results of gender comparisons of students at

School A, School B, and the combined sample, respectively. Comparisons were made using a 2-tailed t-test for independent samples. The level of significance established for the study was $p \leq 0.01$.

Table 4

Gender Comparison of NSKSE Results—School A

	Males (n = 9)		Females (n = 8)			
	Mean	S.D.	Mean	S.D.	t-value	Sig.
Creative Subscale	21.56	2.40	22.75	1.98	1.109	0.285
Developmental Subscale	21.44	3.50	20.13	3.04	0.823	0.488
Testable Subscale	24.33	3.54	24.13	3.87	0.116	0.909
NSKSE	67.33	5.07	67.00	6.09	0.123	0.904

Table 5

Gender Comparison of NSKSE Results—School B

	Males (n = 12)		Females (n = 9)			
	Mean	S.D.	Mean	S.D.	t-value	Sig.
Creative Subscale	19.25	3.05	19.78	2.17	0.441	0.664
Developmental Subscale	23.17	2.17	22.11	1.17	1.319	0.203
Testable Subscale	20.33	2.61	21.11	2.71	0.665	0.514
NSKSE	62.83	4.17	63.00	3.12	0.100	0.921

Table 6

Gender Comparison of NSKSE Results—Combined Samples

	Males (n = 21)		Females (n = 17)			
	Mean	S.D.	Mean	S.D.	t-value	Sig.
Creative Subscale	20.24	2.96	21.18	2.53	1.034	0.308
Developmental Subscale	22.43	2.87	21.18	2.40	1.435	0.160
Testable Subscale	22.05	3.58	22.53	3.56	0.413	0.682
NSKSE	64.76	5.01	64.88	5.04	0.074	0.942

These results indicate no significant differences between the male and female grade six students surveyed with respect to their understanding of the nature of science as measured by the NSKSE.

Effects of Prior Science Curriculum

Scores for students from School B ranged from a low of 55 to a high of 68, with a mean of 62.9. Scores for students from School A ranged from a low of 60 to a high of 79, with a mean of 67.2.

This study does show significant differences between the two classes, with students involved in the long term curriculum innovation (School A) scoring significantly higher with respect to their understanding of the nature of science as measured by the NSKSE. The results of the data analyses are shown below.

Table 7

School Comparisons of NSKSE Results

	School A (n = 17)		School B (n = 21)		
	Mean	S.D.	Mean	S.D.	Sig.
Creative Subscale	22.12	2.23	19.48	2.66	0.002
Developmental Subscale	20.82	3.26	22.71	1.85	0.031
Testable Subscale	24.24	3.58	20.67	2.61	0.001
NSKSE	67.18	5.40	62.90	3.67	0.006

Results of the NSKSE indicate that students involved in the elementary science curriculum innovation scored significantly higher on the NSKSE on the creative subscale ($p = 0.002$), the testable subscale ($p = 0.001$), and overall ($p = 0.006$) than their peers. Students from the two schools showed no significant difference ($p \leq 0.01$) on the developmental subscale.

While the school results on the developmental subscale does not follow the trend for the other subscales and the overall NSKSE scores, there are possible explanations that account for this. These issues will be dealt with in Chapter 5.

Interview Results

While the quantitative data offer an opportunity to examine and compare students' understanding of the nature of science in a generalized way, the interviews offer a chance to investigate and describe more fully the range of student positions with respect to understanding the nature of science and the nature of scientific knowledge.

Subjects were chosen to participate in the interview on the basis of their NSKSE results. Those selected were the male and female students from each school with the highest and lowest NSKSE results. When referring to individual students, each will be identified by a three-letter abbreviation. The first letter indicates whether the student scored at the low (L) or high (H) end of the continuum on the NSKSE. The second letter indicates gender (M or F) and the third indicates whether the student attended School A or School B (A or B). The following table lists the eight students involved in the interviews and their subscale and NSKSE scores.

Table 8

NSKSE Results for the Interview Subjects

Student	Creative Subscale	Developmental Subscale	Testable Subscale	NSKSE
LMB	17	24	14	55
LFB	19	22	17	58
LMA	20	20	20	60
LFA	21	22	18	61
Mean	19.0	21.25	18.25	58.5
HMB	19	25	24	68
HFB	25	20	23	68
HMA	25	26	23	74

HFA	26	25	28	79
Mean	23.75	24.0	24.5	72.25

Subjects were chosen for the interviews because they represented the extreme scores for this sample on the epistemological continuum defined by the NSKSE. Therefore, for the purposes of analysis and reporting the subjects were grouped based on their NSKSE scores, with the four low-scoring subjects constituting one group and the four high-scoring subjects constituting the other. The selection process did result in the selection of students with a range of positions, as indicated by the NSKSE.

Views Regarding Theories

As indicated previously, the semi-structured interviews were set in the context of a science activity. An initial set of questions or probes dealt first with the specific context used (Amanda's theory about oils). Later questions dealt with theories more generally. The questions were designed to determine if students understood that theories are explanations for physical phenomena, that they are created by scientists, that they are based on some prior knowledge or understanding, and that experiments are designed to be tests of theories.

Students were shown three bottles containing different types of oil; corn oil (the darkest), canola oil, and sunflower oil (the lightest). The bottles were labeled as to their contents. Students were then read the following scenario: *Amanda has a theory about oils. She believes that some oils are thicker or heavier than others, and that this makes the oils behave differently. She also believes that thicker (heavier) oils will be darker than thinner (lighter) oils.*

Students were asked if they agreed with Amanda's theory or not, and were asked to explain why they agreed or disagreed. They were then asked a series of follow-up questions about theories in general.

All four of the low-scoring students agreed with Amanda's theory, with one student being less certain than the others. The reasons given for the agreement varied. Two students (LFA & LMB) agreed despite not being able to identify any reasons for doing so. A third student (LMA) based his agreement on prior experience with motor oil. He stated that, "most oil, it is dark. Like motor oil, it is dark and thick." The student was able to give an example of an oil that was both thick and dark but when asked if he could think of any other evidence to support or contradict Amanda's theory, he replied that he could not. Despite being asked for more evidence, the student offered only the example of a dark-coloured motor oil that was thick. While this example is certainly consistent with Amanda's theory and supports it, his rationale would have been stronger if he had contrasted it with an example of a light-coloured thin oil as well.

The remaining student, LFB, was less certain of her agreement with Amanda's theory. She was also unable to supply any evidence that would support it. However, she did allude to a potential explanation for the different oils.

Interviewer: Do you believe her theory? LFB: Kind of.
Interviewer: Why do you say "Kind of?" LFB: Because the lighter one might not have as much in it as the heavier one, because it is darker. It has more..[fades off and does not complete sentence]
Interviewer: So is that why you "Kind of do believe it, or kind of don't?" LFB: Yeah.
Interviewer: Which one? LFB: Probably do.
Interviewer: Because the lighter one might not have something in it? LFB: Yeah. Calories and stuff.
Interviewer: Can you think of any evidence that could support her theory? LFB: [no reply]
Interviewer: Anything that you've seen or that might go against her theory? LFB: Well, this oil here [points to the middle colour] is in between, kind of, so they might have

mixed some of both of them and put it in that one.

On probing, the student was unable to explain how or why the extra ingredients would cause the relationship between colour and viscosity of oil. This was also true of questions later in the protocol. For her, the notion that extra ingredients served as a possible explanation for differences in the colours of the various oils seemed to be enough to answer the question. She did not seem to understand that her explanation should be able to account for how the extra ingredients caused both properties of oil under investigation—colour and viscosity, and therefore made no attempt to do so.

Three of the four low-scoring students had a great deal of difficulty discussing theories in general. Student (LFA) was typical of these students.

Interviewer: What is a theory? LFA: [no reply]
Interviewer: What do you think a theory is? LFA: I don't actually know what a theory is.
Interviewer: What ideas do you have about theories? LFA: That it's...[fades off and does not complete the sentence]...If you look at something, you can get a theory out of it...And there's different kinds of theories. Scientists make different theories to. When they make different theories, that's like different creation to it.
Interviewer: What do you mean by that? LFA: Here [points to the three bottles of oil], they could have made three different theories. This one [corn oil] could be different created than the lighter one. Maybe they put more stuff in that one [darker oil] than that one [lighter oil].
Interviewer: What is the purpose of a theory? LFA: [no reply]
Interviewer: So scientists create theories, right? What's the purpose of a theory? LFA: Um..[no reply]
Interviewer: When you are doing science, do you create theories? LFA: Sometimes.
Interviewer: So why do you do that? LFA: [no reply]

LMA also had great difficulty discussing theories. He did indicate that scientists create theories to find out more about something but he could not describe what a theory was or give an example of one. LMB indicated that theories and experiments are involved in trying "to find out more about something." However, as with the previous student, he did not distinguish between theories and experiments, he gave no indication of what theories or experiments are, what role they play in science, or how they are related to one another. In short, his responses fit the stereotypical description in the literature.

The third student (LFB) also indicated that scientists were the source of theories but she could neither identify what a theory was, nor its function. As with the previous two students, it was often not clear when she was talking about a theory and when she was referring to the physical entity. Like the previous two students, she also lumped theories and experiments together in a vague process often referred to as "It."

The fourth student (LMB) also identified theories as being created by people.

Interviewer: What is a theory? LMB: I don't know. Something that someone thinks, or something like that.
Interviewer: Why do scientists create theories, do you think? LMB: To see what happens when you experiment with them.
Interviewer: So what's the purpose of a theory? LMB: I don't know.
Interviewer: Any idea? LMB: No.
Interviewer: Once a theory is created scientists usually try and test it. How do you think that scientists try and test theories? LMB: I don't know. By using their imagination and stuff.
Interviewer: Anything else? LMB: Nope.
Interviewer: You don't think that there are other ways that they could test it? LMB: Mixing them or something like that.
Interviewer: What do you mean by that? LMB: Take some kind of thing and mix them together to see what happens.
Interviewer: What is a theory? LMB: I don't know.
Interviewer: What is an experiment, in science? LMB: When someone is mixing the stuff, or just trying different ideas.

While the student claims not to know much about theories and experiments he did have some interesting ideas. He stated that a theory was, "Something that someone thinks," indicating that a theory was tentative and therefore perhaps different from something that someone knows. He also indicated that scientists create theories "to see what happens when you experiment with them." When probed, he indicated that he believed theories and experiments to be separate things but he could not describe what they were, what their purposes might be, or how the two were related. While this student, like the previous three, understood very little about theories and experiments, he at least understood that the two were not the same thing. In this respect his views were more sophisticated than the other three low-scoring students.

In general, the low-scoring students did not demonstrate an understanding that theories are ideas or potential explanations for physical phenomena. They also did not indicate that experiments are intended to be tests of those theories. Their answers showed little evidence that they differentiated between theories and experiments and so it is not surprising that they could not distinguish between the two with respect to their functions in science. Low-scoring students made few, if any, references to the empirical nature of science. Any references to experiments described the open-ended unknowing position that Solomon et al. (1994) referred to as "mindless experimentation." In this respect. these students did not seem to understand the testable nature of scientific knowledge.

The high-scoring students, like their lower-scoring peers, showed some variability with respect to support for Amanda's theory. Two of the four high-scoring students agreed with Amanda's theory, while the other two expressed far more tentative support for the theory.

Of the students who agreed with Amanda's theory, one (HMA) did so, "...because like Crisco, baking oil is light, like this [points to the sunflower oil, the lightest in colour], and it's runny. But then you get black car oil and it's thicker." In this case the student cited previous experience with oils as the primary reason for agreeing with Amanda's theory. However, unlike the student from the previous group (LMA), this student gave examples of both a dark-coloured thick oil and a light-coloured thin oil and used the examples together in his explanation.

The other student (HFA) who agreed completely with Amanda's theory made reference to previous experience with oils that was consistent with the theory. She also had a potential explanation for the differences between the two oils.

Interviewer: Do you believe her theory? HFA: Yes.
Interviewer: Why do you believe that her theory is true? HFA: Well, thicker oils are darker and lighter [thinner] oils are lighter [in colour]. I kind of think that because if you look at lighter [thinner] oils they are light [coloured], because they don't have as much [voice trails off and she doesn't complete the sentence].
Interviewer: So, does lighter colour also mean lighter oil? HFA: Sometimes, yes...because I think that darker oils means that it is heavier because it has more molecules and stuff in it. And then the lighter ones have less molecules and they are just simple and basic...and they would have less ingredients.

While the proposed explanation (extra ingredients) was the same as one of the students in the previous group (LFB), HFA's answer related the two properties of oil being investigated together on the basis of one explanation—extra ingredients (molecules) that account for both properties.

One of the remaining students in this group agreed with the theory, but did so with reservation. He (HFB) responded as follows:

Interviewer: Do you believe her theory? HMB: Yeah, I guess.
Interviewer: Is that a yes, no, or I don't know? HMB: Yes.
Interviewer: Why do you believe that it is true or why you agree with it? HMB: Well, they might react differently because of the different colours, or heavier or thinner, and, um, You know, they might react differently, they might not.
Interviewer: What about the bit about the darker one being thicker. Do you agree with that part? HMB: Not necessarily, because the lighter [coloured] one could be thicker. You have to test it.

His responses to these questions indicated that he did not completely understand Amanda's theory. He seems at times to understand that the theory establishes a relationship between thickness and viscosity in oil, yet some of his answers imply that parts of the theory could be true and not others. This confusion is evident in later parts of the protocol. While he indicated that he required more evidence in the form of testing before he was willing to agree that the theory was true, his understanding of the theory was more limited than his high-scoring peers.

When asked about Amanda's theory, the fourth student (HFB) responded as follows:

Interviewer: Do you believe her theory? HFB: Not..[pauses] Well, yeah, I guess. [unsure tone and body language]
Interviewer: You don't seem sure. How come? HFB: Well, it looks darker, and like, more dye in it.
Interviewer: Do you have any evidence to support her theory? HFB: No, not really. There is no evidence that it is true.
Interviewer: Originally you said "Not...Well, yeah, I guess." Let me re-ask the question. Do you believe in her theory? HFB: No. Not really.

While the student agreed that the darker oil appeared to be thicker, she did not consider this sufficient evidence or justification to agree with Amanda's theory. Unlike the student from the preceding group, she did not consider the observation of the colour difference and the potential explanation of extra dye or ingredients as sufficient warrant for belief in the theory. Although she indicates that there may be a potential explanation that relates the two properties of oil together, this was not sufficient justification for acceptance of the theory. She still required more evidence.

The four high-scoring students were more diverse in their views about theories and experiments. They also tended to give more information in response to questions. With respect to theories in general, the first student (HMA), like the previous group, implied that theories are created by scientists. However his responses to other questions were quite different from the first group. He responded as follows:

Interviewer: If we said that a scientist has a theory, what would we mean? HMA: That he believes in his, er, he believes what he is saying. That he figures out that two things mixed together makes acid, or something. That his theory, and he believes in that.

Interviewer: Why do scientists create theories? What is their purpose? HMA: So they can make the world better.
Interviewer: So what role does a theory play in that, do you think? HMA: He is telling people that this is how he figured it out to be. That this is his theory.
Interviewer: So it is the scientist's explanation? HMA: Yeah.
Interviewer: Once a theory is created scientist usually try to test it. HMA: Yeah. [in agreement]
Interviewer: How would you test a theory? HMA: Well, if they got the thing made already, and then they try to make it again. And if they can, they stick with that theory.
Interviewer: So what if I made a theory and never tested it at all? HMA: You'd have to test it.
Interviewer: And how would I do that? HMA: See if it was, like acid. [refers to his previous example]
Interviewer: Well, let's say that I have a theory that heavier objects fall faster than lighter objects. HMA: Have to test it! [emphatically]
Interviewer: How would I do that? HMA: Take a light object. Take a heavy object. Drop them, at the same time, same level [indicates by putting both hands equal distances from the floor]. Like a feather and a brick and drop it at the same level, same time.
Interviewer: And? HMA: Test it.
Interviewer: And how would I know if my theory is correct? HMA: You'd have to do it more than once.
Interviewer: Ok, but does it matter what results I get? HMA: If you dropped the brick and it landed first, then you know that heavier things go faster.
Interviewer: What is an experiment? HMA: An experiment is when you mix stuff together to get something else.
Interviewer: Is that the only kind of experiment? HMA: No, there's...not sure.

This student referred to theories as ideas or explanations. "He [the scientist] is telling people that this is how he figured it out to be." Likewise, the example that he used demonstrated the same separation. "He figured out that these two things mixed together makes acid." It is important to note that he was not referring to the acid as the theory. Instead the theory refers to what he has "figured out." There appears to be some confusion in his answers regarding testing of theories. When indicating how he would test his acid theory he indicated that he would test it, referring either to the acid or to the idea that two particular things mixed together make acid. The wording of his answer implies that he was testing the idea, not the substance. However, to confirm this, the student was asked how he would test the theory that heavier objects fall faster than lighter ones. In his description of the experiment and the interpretation of the results, his example is consistent with theories being ideas or explanations and experiments being tests of those ideas. Yet, when he was asked what an experiment was, his answer did not relate to testing of theories. Instead, it related to the phenomenon. He did indicate the end product of the test is that you know that your theory was correct. "Then you know that heavier things go faster."

This student also made reference to theories being tentative ideas that are held by individuals. In his description of theories he stated that a theory was an idea that was the personal creation of the individual scientist. He stated that, "This [the explanation] is how he figured it out to be...this is his theory." He also indicated that a scientist's theory, what he thinks, can eventually be shown to be "true." He stated that, "A theory is what you think something is, but you don't necessarily know for sure. It is what we think, but not necessarily true."

The second student (HFA) showed a similar distinction between theories and experiments, but her explanations were much clearer and more well defined.

Interviewer: What is a theory, in science? HFA: A theory is what you think something is, but you don't know for sure. It's what we think, but not necessarily true.
Interviewer: Why do scientists create theories? HFA: To explain scientific things. Like if you are studying the moon or something. Just to explain something.
Interviewer: So once a theory is created, what do they [scientists] do with it? HFA: They use it to find out more about this certain thing that they are studying.
Interviewer: So how do scientists try and find out if the theory is true? HFA: They experiment.
Interviewer: So when scientists test theories? [questioning] HFA: They are basically testing what they think.
Interviewer: How would you test a theory? HFA: Well, if I was studying the moon, I would try and make a moon [indicates a circle with her arms] and try to get it to a special place where there wouldn't be much oxygen, like a tank or something. And then I would test how well plants live on it, or little flowers, or stuff like that.
Interviewer: And how would that test your theory? HFA: Let's say that my theory was that I think that living plants, and stuff like that, could live on the moon. So I test it by

putting them in an environment that the moon would live in and put the plants in with it.
Interviewer: Do experiments have anything to do with theories? HFA: Well, sometimes when you do an experiment it is to see if a theory is true.
Interviewer: Ok. What might be some of the other purposes of doing experiments?
HFA: Testing to see if they work, to see if they are safe, or whatever.
Interviewer: To see if what is safe? HFA: Like, if we were testing a new source of medicine. You would test it before, to see if it were safe.
Interviewer: So, if you are not testing a theory, you are testing? [questioning] HFA: Things.

Her examples and explanations described a view of science as an activity involving model and theory building, followed by experimentation on the model. The evidence gained in examining the model is then used to evaluate the feasibility of the theory. According to her, the end product of this process is the determination of the truth or falseness of the theory. Interestingly, she did not describe experiments which involved product or safety testing as tests of ideas, rather, she indicated that these were tests of things.

The remaining two students, both from School B, were not able to describe theories and experiments as fully as the first two.

Interviewer: What is a theory? HFB: [no reply]
Interviewer: What is a scientific theory? HFB: I don't know.
Interviewer: What do you think a scientific theory is? HFB: What they believe.
Interviewer: What is it they believe in? HFB: That its true or that it..[fades out and does not complete sentence]
Interviewer: Why do scientists create theories? HFB: So they can experiment.
Interviewer: So what's the purpose of the theory? HFB: So they try and find out if they are right.
Interviewer: Guess if what? HFB: Guess if [inaudible]
Interviewer: Once a theory is created scientists usually try to test it. How do scientists test theories? HFB: Do an experiment with it.
Interviewer: So what is an experiment? HFB: To try things out to see what happens.
Interviewer: How does the experiment relate to the theory? HFB: They try it and see if they are right.
Interviewer: So when you say try "it," what are you referring to? HFB: You try and see if the theory is right.
Interviewer: When you say "It" you mean the experiment? HFB: Yes.

While the student's answers were not overflowing with descriptions and examples, she did communicate some basic ideas about theories and experiments. For example, her answers differentiated between theories and experiments. She also indicated that theories describe what scientists believe and that an experiment can tell the scientists if they are right. However, like HMA, her description of an experiment was inconsistent with some of the responses, since it did not indicate a linkage to theories.

The last student (HMB) differentiated between theories and experiments, but this distinction was not always evident in his descriptions and explanations. In many other respects his views on theories and experiments showed similarities to the low-scoring group. For example, he did not indicate the purpose of either theories or experiments. Unlike the other three high-scoring students, he did not relate the process of science to increased understanding. Also, his description of an experiment made no reference to theories. The differences between this student and the other three high-scoring students were somewhat surprising. However, HMB's score on the creative subscale more closely resembles the low-scoring students than it did the remaining high-scoring ones (see Table 8). Thus, it may not be surprising that HMB could not explain what theories are or why they are created.

Three of the high-scoring students demonstrated an understanding of theories and experiments and the relationship between the two. Two of these students, HMA and HFA, stressed the importance of experimentation and the empirical nature of science.

Comparison of Low- and High-Scoring Groups

Two students in the low-scoring group (LFA & LMB) agreed with Amanda's theory despite the fact that they could not provide any reason to do so. One of them (LMB) had a score of 14 on the testable subscale, the lowest of any student in the sample, and one of only three subjects who scored below the midpoint on the testable subscale. A third student (LMA) agreed with the theory and provided evidence that supported part of it (an example of a dark, thick oil), and the fourth (LFB) tentatively agreed with the theory and came up with an explanation for part of the theory (heavy oils have more ingredients than light oils) but she did not attempt to relate the explanation to the other property of oils under investigation—colour.

Of the four students in the high-scoring group, two agreed with Amanda's theory. The first (HMA) provided examples of both a dark-coloured thick oil and a light-coloured thin oil, thus relating the two properties of oil together. The second student (HFA) gave a rationale that was very similar to that of LFB. The only differences were that she used the term molecules for the extra ingredients (rather than calories) and her explanation related both properties of oil to the presence or absence of these extra ingredients.

The other two high-scoring students were more reserved in their judgements. One student (HMB) gave tentative support to the theory but indicated that you would have to test it to see if it were true. The last student (HFB) provided a potential explanation very similar to student LFB, however, she did not consider this sufficient cause for agreement and later indicated that she did not believe Amanda's theory. Compared to LFB, it would appear that HFB required a higher level of supporting evidence before she would agree with the theory. This indicated a position more consistent with the testable aspect of the three-factor model. On the NSKSE, student LFB was one of only three subjects in the entire sample who fell below the midpoint on the testable subscale, with a score of 17, while HFB scored 23 on the testable subscale, which was above the mean for the combined sample.

None of the students from the low-scoring group were able to provide evidence or an explanation that supported or explained both aspects of Amanda's theory, yet all four students still stated that they believed her theory. All four of these students scored below the mean on the testable subscale of the NSKSE (n = 38), with two of the students (LFB & LMB) receiving the two lowest scores on the testable subscale for the entire sample. These low-scoring subjects were consistent with previously cited research describing students this age. For example, Inhelder and Piaget (1958) concluded that students this age lacked the logic required to evaluate and make judgements about hypotheses. Likewise, Kuhn and Phelps (1982) concluded that students this age could not differentiate between data that is confirming or disconfirming of a particular theory.

The higher-scoring students, however, did not seem to be the naïve realists portrayed in the literature. The decisions that they made to agree or disagree with Amanda's theory were relatively defensible. For example, HMA agreed with the theory because it was consistent with his previous experience with oils, that is, darker-coloured oils (like motor oil) were thick and light-coloured oils (like Crisco) were thin and runny. HFA put forward an explanation for the properties of colour and viscosity in oil that related the two. "Darker oil means it is heavier because it has more molecules and stuff in it." The remaining two students had supporting evidence or explanations similar to students in the low-scoring group. Where they differed, however, is in the decision that they arrived at with respect to their belief in Amanda's theory. The two high-scoring students determined that more evidence was required before they were willing to agree with the theory.

To this point in the analysis, the high- and low-scoring groups have been quite distinct, with the subjects in each group showing a relatively high degree of commonality in their positions with respect to the nature of science and the nature of scientific knowledge. To some extent, in this section of the protocol there were three levels of understanding demonstrated. The lowest level was typified by LFA, LMA, LFB, and to some extent LMB. All four of these low-scoring students stated or implied that scientists create theories. However, only one of the four (LMB) associated theories with ideas, referring to them as "Something that someone thinks." Since they did not indicate that theories were ideas, therefore, the students could not discuss whether these ideas were tentative or not. None of the four could or did determine the purpose or role of theories in science. Also, none of them differentiated between theories and experiments. Instead, they tended to lump the two processes together. Their descriptions of experiments were superficial and stereotypical, with references to mixing liquids in test tubes. The purpose of experiments was related to trying things out or making them work. Solomon et al. (1994) described this as the "cartoon view of mindless experimentation" (p. 366).

The four high-scoring students showed much more diversity in their descriptions and responses. As with the previous group, all four either stated or implied that scientists create theories. All four also stated or implied that theories are ideas. However, only two, HMA and HFA, indicated that theories were tentative ideas or explanation created to help scientists "find out more." These two students represented the high end of the continuum. Both of them referred to experiments as being purposefully structured to be tests of theories and both were able to provide examples that illustrated their understandings. These two students reflected a strong empirical view of science.

The remaining two students, HMB and HFB, represented a middle position. They indicated that a theory is what someone "believes" or "thinks." The choice of words differentiates a theory from something that you know. This is confirmed later in the protocol. The only purpose that they could attribute to theories was that they allowed scientists to test or experiment, but they could not or did not indicate how or why this happens. They also did not indicate that science was about learning or understanding. Therefore, they did not describe experiments as being structured around the testing of theories. Instead, their descriptions of experiments and their purpose bore many similarities to the low-scoring group.

The positions that students HFA and HMA demonstrated with respect to their understanding of scientific theories and experiments were not only significantly different from the other six students, they were significantly different from the descriptions in the literature of students this age. The fact that these two students scored very high on the NSKSE (79 and 74. respectively) reflects well on the NSKSE's ability to discriminate between students on the basis of their views of the nature of science. As well, the fact that these two students were both from School A has implications for the role of science curriculum in developing students' understanding of the nature of science.

Views Regarding the Role of Predictions in Science

One of the topics dealt with in the protocol was students' views of predictions and the role of predictions in science. This was a direct extension of the section involving theories and experiments. It allowed students who have some understanding of the relationship between theories and experiments to explain the role of predictions in evaluating scientific theories. As such, it provided an opportunity to corroborate or validate the findings of the previous section.

Based on the previous discussions regarding theories and experiments, it was expected that the lower-scoring students would have difficulty explaining the function of predictions in testing theories. This was essentially the case.

Interviewer: How do scientists decide what predictions to make? LFA: Maybe they have some stuff already created by scientists in books and they just try to make something different with that, with the same materials in it.
Interviewer: So, in order to make a prediction we have to...? [waits, questioning] LFA: [no reply]
Interviewer: ...know something about it already? [paraphrases LFA's first response]
LFA: Kind of. Yeah. [unsure]
Interviewer: So why do scientists make these predictions? Why are they important?
LFA: So that they try something and they might not know yet if it is poisonous. So they have to try it before they can hurt anybody else.
Interviewer: Ok. So why is the prediction important? LFA: So no one else can get hurt or anything.
Interviewer: Are predictions important in experiments? Yeah.
Interviewer: Why is that? Let's say that we didn't expect it to be dangerous or poisonous.
LFA: So somebody knows about it, but that it can't really break or..[fades off and doesn't complete the sentence]
Interviewer: You said that an experiment was when you try some thing and see if it works. Do scientists make predictions before they try? LFA: Yeah.
Interviewer: So why would they do that? What do you think? LFA: To see if they can..[pauses]..It's kind of hard to explain.
Interviewer: Try. LFA: Like, we would predict, if we could, predict a number in math and see if it's right. Like, if I predict that it might be right, or..[fades off and did not complete the sentence]
Interviewer: Ok. So I have a theory and I predict something. What happens if that prediction comes true? LFA: You probably will be really happy that it worked out.
Interviewer: What does it mean for the theory? LFA: [no reply]
Interviewer: Don't know? LFA: No. [laughs and shakes head]

The student's references to predictions and experiments indicate that she was not distinguishing between the phenomenon itself and predictions or experiments related to the phenomenon. She also did not associate predictions or experiments to theories, even though the interviewer's probing questions guided her in that direction. Earlier in the protocol this lack of distinction was evident when she stated that, "An experiment is when you try something and it works." Upon probing she was unable to expand upon what she meant by the statement.

Student LMA had a difficulty answering any questions related to predictions. He could not or did not indicate any understanding of predictions as they relate to science. LFB had similar difficulties, however, she indicated that scientists do not normally make predictions before they do experiments. Student LMB, who showed some differentiation between theories and experiments in the previous section, continued to do so in this section. However, he showed no understanding of the role of predictions in science.

In all cases the low-scoring students demonstrated no understanding of the role of predictions in science. Given their inability to distinguish between theories and experiments in the previous section, this is not surprising. The views that they expressed on theories and experiments were consistent with those previously expressed.

In comparison to their low-scoring peers, the four high-scoring students had earlier articulated considerable understanding of scientific theories and the role of theories and experiments in science. Therefore, it was expected that they would have more insight into the role of predictions in science. This was, in fact, the case.

Student HFA was very articulate in her description of theories and experiments in the previous section. It was therefore expected that she would be able to demonstrate some understanding of the role of predictions in testing theories.

Interviewer: How do scientists decide what predictions to make? HFA: It depends on what you study. If you are studying sunflowers you could take the sunflower and make predictions about how it would grow inside, under the seeds, like, the roots.
Interviewer: How would you know what predictions to make about how it's growing inside? HFA: You would have to know a little bit about flowers and how they grow and how their roots systems work.
Interviewer: So basically, from some sort of understanding you try and [pauses, questioning] HFA: Predict. Yeah.
Interviewer: Why are predictions important in science? HFA: Well, I guess that they are important because if you don't make a prediction then nobody knows what you think, and it's important that everybody knows what you think.
Interviewer: Are predictions important for doing experiments and testing things? HFA:

Yes. Depending, if you went to make a prediction about something then it gives you an idea about what you think. So it would give some help along the way.
Interviewer: So what happens if your prediction comes true? HFA: Then I would say that you have a very good scientific mind if you could make a prediction and it could be true. That means that you have a good idea of what you are studying.
Interviewer: ...and if your prediction comes true? HFA: Then you know a lot about that thing and if it doesn't come true you should study it some more.
Interviewer: Is a prediction a complete guess, or is it based on [interrupted] HFA: It's kind of like a guess, and truth. What you know, and what you think might happen.

While HFA does not relate predictions to theories, she does indicate that predictions are based on existing understanding, that they are related to experiments, and that the results of the experiment can help you determine, through the prediction, whether or not you understand the phenomenon under investigation.

HMA had also previously demonstrated a well-developed understanding of theories and experiments, and the relationship between the two. As expected, he was able to describe the role of predictions in science.

Interviewer: How do scientists decide what predictions to make? HMA: By studying the object or thing, and then after they study it for a few months or a year, or whatever, then they start predictions.
Interviewer: So what it is that they have done in that time that allows them to make predictions? HMA: Studied it. Took notes on it. Read up about it and studied it.
Interviewer: Why are these predictions important to the work that scientists do? HMA: Because if they just make something up and say that this is how it is, and they try to show it off to other scientists, the other scientist, the other scientists says, "Where's your evidence?" "Where is your predictions?" "How do you know that it does this and that?"
Interviewer: So what do you do with your predictions? HMA: You show it to the other scientists and tell them that this is what I predicted and then show them and they might start believing you.
Interviewer: What do you show them? Just the prediction? HMA: Show them the prediction and what you got after the predictions.
Interviewer: ...What does it mean when a theory is true? [taken from the next section of the protocol] HMA: That their theory is that these two things mixed together will make a different coloured liquid, or make acid. And if they do mix it and it makes it, their theory is true.
Interviewer: So, can we say the same thing in a more general way? When a theory is true, what does it mean about the theory? HMA: That it works.
Interviewer: What do you mean by "works?" HMA: Take them two objects and mix it together and it works.
Interviewer: So what it says will happen..[pauses]? HMA: Yeah. If you write it down

that these two objects will make gas, or whatever, and it does, your prediction was true. You predicted it and then you got it.

HMA was far more descriptive than the other students in relating the role of predictions in science. He indicated that predictions are important and he focused on the role of predictions in convincing other scientists that your idea, your theory, is true. HFA also made comments relating to the importance of communicating your predictions to others. Neither HFA nor HMA came out and stated that predictions are based on theories, however, both implied it in either their examples or their answers to questions.

Since the high-scoring students from School B described theories and experiment in a manner that was between the low-scoring group and the high-scoring students from School A, it was expected that a similar trend would continue in this topic.

Interviewer: How do scientists decide what predictions to make? HFB: They can observe it.
Interviewer: Anything else? HFB: They can test it.
Interviewer: Before they do the experiment? HFB: Yes.
Interviewer: Tell me, why are these predictions important? HFB: So they can see what happens.
Interviewer: So what's the role of predictions in that? HFB: [no reply]
Interviewer: Don't know? HFB: No.

Her answers do not indicate any further understanding of theories, experiments, or the role of predictions in science. Likewise, HMB's answers indicate a lack of understanding of what predictions are and why they are important in science. They also shed no new light on his understanding of theories and experiments.

Interviewer: How do scientists decide what predictions to make? LMB: I'm not sure.
Interviewer: What sort of things might they sue to decide? HMB: Other people's ideas.
Interviewer: Anything else? HMB: [no reply]
Interviewer: Why are these predictions important? HMB: Because they might discover new things and might solve problems in life.
Interviewer: What does that have to do with the prediction? HMB: I don't know.

Comparison of Low- and High-Scoring Groups

Since the low-scoring students had not clearly differentiated between theories and experiments it was anticipated that they would not be familiar with the role of prediction in science. This was essentially the case. In contrast, the high-scoring students from School A indicated that predictions are important in science, that they are based on our existing understanding, that they can help us evaluate our current understanding of a phenomenon, and they stressed the importance of the empirical, testing nature of science. For example, HFA indicated that successful predictions indicated that you have a good understanding of the phenomenon under examination, while HMA indicated that successful predictions mean that the theory is true, "You predicted it and then you got it."

Students HFB and HMB did not demonstrate an understanding of the role of predictions in science, however, they continued to demonstrate a distinction between theories and experiments.

Views Regarding the Status of Scientific Knowledge

Part of the protocol dealt with the status of scientific knowledge. It attempted to determine if students held absolute views of scientific knowledge or if their views were more developmental and evolutionary in nature. While the literature indicates that students this age are naïve realists and therefore have absolute views of knowledge, the average scores on the NSKSE indicated that the students believed that science was developmental in nature.

The four low-scoring students all indicated that the results of the test or experiment would determine if the theory were true or false. However, they all had difficulty explaining how and why this determination is made.

Interviewer: Which of these statements better describes what happens to a theory after it has been tested?
A) The results of the test/experiment will increase or decrease the scientist's confidence in the theory. OR B) The results of the test/experiment will prove the theory to be true or false? LFA: Theory to be true or false.
Interviewer: What does it mean if a theory is true? LFA: When it's true people can create more and if it would be false they wouldn't have as much fun with it because it wouldn't work.
Interviewer: What do you mean by work or not work? LFA: Like when you buy something, like a radio or something, and it doesn't work. It would be something not useful and they just cheated you.
Interviewer: So what if a theory isn't true or doesn't work? What does that mean? LFA: That the scientists can try it and the people say it works.
Interviewer: So if a theory works? What does that mean? LFA: [no reply]
Interviewer: Can scientists accept a theory even if it can't be tested? LFA: No.
Interviewer: Why not? LFA: Because that would be something that wasn't able to be near.
Interviewer: Let's say that I have a theory about the moon, but I can't test that theory. Can we still believe it? LFA: Yeah.
Interviewer: Do we know if it is a true theory? LFA: No. Not really.
Interviewer: Can we accept a theory and believe in it even if there is no evidence to support it? Yeah. Interviewer: Can we decide if it is a true theory or not? LFA: No

LFA indicated an absolutist view of scientific knowledge, but she distinguished between an individual's belief in a theory and that theory being "true." LMA exhibited similar views.

Interviewer: Which of these statements better describes what happens to a theory after it has been tested?
A) The results of the test/experiment will increase or decrease the scientist's confidence in the theory. OR B) The results of the test/experiment will prove the theory to be true or false? LMA: The last one you said.
Interviewer: What does it mean if a theory is true? LMA: That you have proof that the theory is true.
Interviewer: And what does it mean if the theory is true and we have proof? LMA: That it is real.
Interviewer: Can scientists be more sure of some theories than others? LMA: Yeah.
Interviewer: What would cause that? LMA: One scientist may have done more tests or different tests.
Interviewer: Can a theory that can't be tested be a true theory? LMA: No.

Similar to the previous student, LMA indicates that an individual scientist can believe in a theory, and even contends that a scientist can be more sure of one theory than another. However, that differed from a "true" theory—one that we have proof for. Thus the student was classified as absolutist, because he indicated that theories could be determined to be true or false. His reasoning regarding the status of scientific knowledge was very circular. He indicated that theories were true if they were proven, and if they were proven they were real, but he never could or did describe what any of these terms meant.

LFB and LMB both indicated that the results of a test or experiment increase or decrease a scientist's confidence in a theory. However, both also indicated elsewhere that theories that "work" are true theories. Like the other low-scoring students, the answers that these students gave were sometimes confusing and seem to indicate inconsistencies within their epistemological positions.

Interviewer: How do scientists decide which theory they have more confidence in? LFB: You test them.
Interviewer: Let's say that you did test the two theories? [pauses, questioning] LFB: One might turn out better than the other.
Interviewer: One test, or one theory? LFB: One theory.
Interviewer: How do you know that it turned out better? LFB: You test it.
What it is about the test that let's you know if the theory is better? LFB: If it works.
Interviewer: And what do you mean by that, "It works?" LFB: If they had a spray that would dissolve it and then if it worked and then if we tried to pour some kind of liquid on the straw and it didn't work but it was close and then they might go with the pencil and start that up.
Interviewer: What does it mean when a theory is true? LFB: That it works and helps them with their thinking and more stuff.
Interviewer: Can scientists accept a theory even if there is no way they can test it. LFB: I don't think so. Can scientists accept a theory even if there is no evidence to support it. LFB: Maybe. Possibly.

Her answers exhibited flaws in her logic. For example, she agreed that scientists may accept a theory with no evidence to support it, yet she also stated that scientists are not able to accept a theory if it can not be tested. Another example was her absolutist reference to theories being true if they work, yet also concluding that a theory is better if it worked.

LMB also indicated that tests or experiments increase or decrease the scientist's confidence in the theory. However, he also referred to theories in absolutist terms as being right or wrong.

Interviewer: Can a scientist be more sure of some theories than others? LMB: Yeah.
Interviewer: How would that happen, or why would that happen? LMA: I don't know.
Interviewer: What does it mean when a theory is true? LMB: It means that they had success or something.
Interviewer: What do you mean by success? LMB: When someone says that you can't do this and that it's impossible. Someone tests it and it's true that you can.
Interviewer: Can scientists accept a theory even if it can't be tested? LMB: Yes.
Interviewer: Can scientists accept a theory even if there is no way to support it? LMB Yeah.
Interviewer: If that theory can never be tested, could it still be a true theory? LMB: Yeah.
Interviewer: Would we ever be able to know? LMB: No.

Despite the fact that two of the four students originally indicated that tests or experiments increase or decrease a scientist's confidence in a theory, all four of the low-scoring students indicated that theories can be determined to be true or false. However, they distinguished this from the lesser status of individual scientists believing in the theory.

All four of the high-scoring students stated or implied an absolutist position with respect to scientific knowledge. Similar to their low-scoring peers, they also differentiated between accepting or believing a theory and the higher status of the theory being true. However, these four were able to indicate far more clearly how experiments are involved in this process. For example, HFA stated that if you could not test your theory you could still believe in it personally, however, "You couldn't say that's the way it is—that it is the way that is has to be. You could only say that after you have tested it and know for sure." HMB also linked physical evidence to explanations being granted the status of "truth". He stated that if a scientist said that something were true, but could not supply any evidence, then he would not believe him. However, if "their theory is that these two things mixed together...makes acid, and if they do mix it, and it makes it, their theory is true."

Student HFB articulated a similar position as the two previous students, however, she could not describe the process by which something is determined to be true. She stated that testing a theory results in it being determined to be true or false. When asked what it meant for the theory to be true she answered "That they were right about it." HFB was then asked, "How will they know if they are right about it?" Her response did not relate to physical evidence. Instead she stated "Well, it's true. They tested it to find out if its true."

The last student, HMB, indicated that testing a theory would increase the scientist's belief in it. When probed he indicated that ultimately the theory could be determined to be true or false, but that this determination could not be accomplished in one experiment.

Comparison of Low- and High-Scoring Groups

In this section of the protocol very few differences were apparent between the two groups of students with respect to the positions held. All eight indicated that scientists could believe in theories, however they distinguished between this status and the enhanced status of a theory being determined to be true. The high-scoring students gave better accounts of how and why this status is achieved, but the basic positions regarding the status of scientific knowledge were essentially the same.

The results indicating that the students were absolutist in their epistemological positions is consistent with the literature, but it is not consistent with the results of the

NSKSE, which indicated that the students agreed with the creative and developmental aspects of the nature of science. Results of the interviews, however, indicate that students do consider science to be creative and developmental, but that this creativity and development are involved in the discovery or confirmation of a true theory.

Students' Epistemologies in Action

The *Oily Peppercorns* activity allowed students to generate data relating to Amanda's theory and subsequently determine if the data collected supported her theory or not. Following the data collection, students were asked to use the experimental results to determine which of the oils was the thickest and which was the thinnest. Following this they were asked to explain why they ranked the oils as they did. They were then asked to determine if their results supported Amanda's theory and why.

The Oily Peppercorns activity tends to generate random data caused by differences in the peppercorns. Two of the four students in the low-scoring group (LFA & LMB) identified differences in the peppercorns as a source of variability within the experimental results. Despite this, they did not question the validity of the experimental results.

When they made decisions about which oil was thickest and which was thinnest, the low-scoring students used two different strategies. One was to use extreme individual results to determine the thickest and thinnest oils. That is, whatever oil had the slowest overall trial was deemed to be the thickest oil and whatever oil had the fastest overall trial was deemed to be the thinnest oil. The second strategy was to use the range or general trend of the data as a guide to determining the rankings. Some students indicated that they had combined both strategies. For example, in comparing two of the oils LFA stated, "Here [points to the sunflower oil results] they are all low numbers. Plus here [points to the canola oil results] we got a really high number like nine [9.35 seconds, the slowest of any trial]."

LFB used only the individual extreme results in ranking the oils' viscosity. LFA and LMA used both strategies. LMB stated that he based his results on the general trend of the data, but in fact, his rankings were not consistent with the mean or range of the results, they were consistent with the individual extreme results.

Based on the results and the strategies that they reportedly used, three of the four students (LFA, LMA, and LFB) correctly ranked the oils' viscosity. However, when asked to determine if the results of their experiments supported Amanda's theory, all four of the students had difficulty making valid conclusions. One student (LFA) ranked the sunflower oil as the thinnest and the canola oil as the thickest, with the corn oil in the middle. When asked if her results supported Amanda's theory, she indicated that they did. When she was asked specifically about the corn oil results she reconsidered and stated that her results did not support Amanda's theory.

LMA also ranked canola as the thickest oil and sunflower as the thinnest. When asked, he indicated that his results did support Amanda's theory. His rationale was that since the results indicated that the lightest oil (sunflower oil) was the thinnest, the experimental results supported her theory. He openly admitted that the remaining evidence was not consistent with Amanda's theory, "because the darkest oil isn't the thickest." This student had originally agreed with Amanda's theory. When asked if the experimental results changed his belief in the theory he indicated that they had and that he no longer believed Amanda's theory. When asked if the results also meant that the theory was not true, he indicated that, "Some of it is and some of it isn't." The student had separated the experimental results into those which agreed with Amanda's theory about darker oils being thicker (sunflower oil) and those which did not (corn and canola oil). This separation of results indicates that the student does not understand that Amanda's theory involving the relationship between oil colour and viscosity is one conceptual whole. He believes that the theory consists of two parts: A) lighter-coloured oils are thinner, and B) darker-coloured oils are thicker. He also believes that it is possible for one of these statements to be true but not the other.

Another student (LFB), based on the experimental results, correctly ranked the corn oil as the thickest and the canola oil as the thinnest. When asked if these results supported Amanda's theory, he indicated that they did not. When then asked if this meant that Amanda's theory was not true he indicated that it did not. According to him, Amanda's theory was true because it was supported by the results indicating that the darkest oil was the thickest. As in the previous case, this student separated the colour-viscosity relationship into two parts: that dark-coloured oil is thicker, and that lighter-coloured oil is thinner. He then focused on the data that supported the first part of the theory: that dark oil is thicker. This rationale allowed him to still maintain that Amanda's theory was true because a part of it was true.

The fourth student (LFB) ranked the sunflower oil as the thinnest and the canola oil as the thickest. She then indicated that these results supported Amanda's theory, when in fact, they clearly do not. Her rationale was that, "The colours were darker and heavier, like, thicker." Here she indicated that the experiment does show a color-viscosity relationship. This contradicted her own results and her own previous rankings based on those results. When specifically asked if the experimental results supported the idea that thicker oil would be darker, she reversed her answer and indicated that they did not. She then concluded that this meant that Amanda's theory was incorrect.

While three of the four low-scoring students were able to use appropriate strategies to rank the viscosity of the oils, none were able to appropriately evaluate whether or not the evidence supported Amanda's theory. These results are consistent with previous research which indicates that students this age fail to differentiate between theories and experiments and lack the logic required for this task (Kuhn & Phelps, 1982; Kuhn et al., 1988).

In some ways the four high-scoring students showed similarities with their low-scoring counterparts. For example, two of the four high-scoring students (HFA & HFB) identified differences in the peppercorns as a source of variability within the experimental results. As well, of the four students in this group, two (HMA & HFB) used only the individual extreme results in ranking the oils' viscosity. One student (HFA) indicated using both strategies. The remaining student (HMB) based his results on the range of the data for each condition.

Three of the four students (HFA, HMA, and HMB) correctly ranked the oils' viscosity based on the results and the rationales given. Two of these students (HFA & HMA) also correctly concluded that their results were not consistent with Amanda's theory. However, they disagreed in concluding what the results of the experiment meant for Amanda's theory. One (HFA) indicated that the experimental evidence "proved [that] her theory was wrong." The other student (HMA) indicated that, "by the evidence that we got" her theory was incorrect. However, he argued that the differences in the peppercorns made him doubt the conclusion to the experiment. When asked if the experimental results made the theory correct or incorrect he replied that, "It don't make it neither...Like I said...the peppercorns might have been different." Therefore, he argued that her theory could still be true.

HMB correctly ranked the oils based on the experimental results, with sunflower oil being ranked the thickest and canola oil being ranked the thinnest. When asked if these results supported Amanda's theory he replied, "Yeah, I guess." When asked to clarify, he indicated that there was evidence that oils varied in thickness. He, like LMA and LFB, had separated the theory into parts and had concluded that the theory was true because the data supported one "part" of the theory. When he was asked specifically about the aspect of Amanda's theory that darker oils were thicker. he indicated that the results did not support the part of the theory. He then reversed his position and indicated that, based on the data, Amanda's theory was not true.

HFB originally concluded that corn oil was the thickest and sunflower oil was the thinnest. However, the individual extreme results, the ranges, and the means all indicated that the canola was the thickest and the corn oil was the thinnest. The student's conclusion was consistent with Amanda's theory, but totally inconsistent with the data. When it was pointed out to her that the slowest trial involved the canola oil and the fastest involved the corn oil, she did change her rankings to agree with the results. When asked if the revised results supported Amanda's theory, she originally responded that they did. She then quickly reconsidered and indicated that they did not. When asked if these results meant that Amanda's theory was incorrect she replied that they did not. Instead she argued, "That it [the theory] could still be wrong or it could be right." She indicated that we might know if it were true or not, "If we tested it more."

Comparison of Low- and High-Scoring Groups

Three of the four students in each group successfully ranked the oils based on the experimental results. The strategies used in doing so were consistent across both groups.

Differences between the two groups occurred, however, when students were asked to apply their results to evaluate Amanda's theory. Only HFA and HMA were able to successfully perform this task. The other six students were consistent with the literature indicating that students this age cannot use data to evaluate theories. However, as was the case in other parts of the protocol, HFA and HMA distinguished themselves from the others and were able to draw valid conclusions based on the empirical evidence available.

Summary

Based on the results reported in this chapter, the following conclusions can be drawn:

1. The two highest-scoring students articulated more developed views of the nature of science than previously described in the literature.

Students HMA and HFA had the highest NSKSE scores of the subjects interviewed. They also articulated the most developed and sophisticated views of the nature of science in the interviews. These two students indicated that one of the main functions of science was the generation and testing of explanations for physical phenomena. They distinguished between descriptions of a phenomenon and explanations for that phenomenon. They differentiated between theories and experiments and were able to articulate a sound knowledge of science processes. They indicated that scientists created predictions based on some prior knowledge or understanding, that experiments were designed to be tests of theories, and that predictions generated by the theories were key aspects of this process.

2. The highest-scoring students were able to successfully evaluate a scientific theory in light of empirical evidence that they had generated.

Most of the students were able to successfully rank the thickness of the oils based on the results of the experiment. However, only the two highest-scoring students (HMA and HFA) were able to evaluate Amanda's theory using the data that they had generated from the Oily Peppercorns activity.

3. All eight students involved in the study held realist views of scientific knowledge.

Despite the range in students' views of the nature of science, all students indicated that they believed scientific knowledge could be determined to be true or false. At times some students indicated that scientists could believe more in one theory than another, or that evidence might increase or decrease a scientist's confidence in a theory. However, those students who articulated a more relativist view ultimately indicated that the end result of the process of science was absolute knowledge. This suggests that the references to belief and confidence were related to an interim position when the correct answer was not yet known.

4. Students from School A, which has a history of extensive science curriculum and teacher professional development, demonstrated more sophisticated positions with respect to understanding the nature of science, than did their peers from School B.

Results of the study indicate that students from a school involved in a long-term science education curriculum project scored significantly higher on the NSKSE than their peers from a matched school where students received a traditional science curriculum. Results also show that aspects of the nature of science featured in the curriculum are the ones that showed significant differences in favor of the project school.

The interviews indicated that the low-scoring students from both schools resembled descriptions in the literature of students this age, with few differences apparent between the subjects from the two schools. The low-scoring students did not differentiate between theories and experiments or between explanations of the real world and the real world itself, did not refer to the various processes of science separately, did not distinguish between theories, predictions, and experiments in their descriptions, and therefore could not explain their functions. Science was most often described as one generic process usually referred to as "It." However, the low-scoring students could not describe how this process occurs except to indicate that if a theory is true "It works." They were unable to describe the role or purpose of theories or experiments in science and were unable to apply appropriately apply experimental findings to evaluate a theory.

However, the high-scoring students showed more diversity in the positions held, with differences tending to correlate with the school attended. High scoring students from School B did differentiate between theories and experiments. While they recognized that theories and experiments were not the same thing, they could not or did not effectively describe the role or purpose of each in science. At times, the high-scoring students from School B differentiated between theories and the real-world phenomena that they were attempting to explain or describe, however, this differentiation was not always apparent, resulting in descriptions of some aspects of science that bore great similarity to their low-scoring peers. The high-scoring students from School B were unsuccessful at applying their experimental findings to evaluate Amanda's theory.

The low-scoring students and the high-scoring students from School B used simple justification strategies that dealt with only part of Amanda's theory, typically the colour. In their descriptions and explanations they did not attempt to establish a relationship between viscosity and colour of oil. Instead, they tended to compartmentalize these two aspects of the theory and deal with them as separate entities. In effect, they agreed with the theory as a whole because they agreed with, and could justify, a portion of the theory.

In contrast, the high-scoring students from School A consistently maintained the colour-viscosity linkage in their descriptions, explanations, and justifications. In general, their descriptions and explanations showed a more developed use of logic that the other students. They also distinguished between the processes of science. They described theories as being explanations for phenomena and experiments as tests of those explanations. They indicated that current understanding and the theory in question are used to generate a prediction and that the comparison between the experimental results and the prediction allow you to evaluate the theory. They also had a strong emphasis on the empirical nature of science. Students HFA and HMA were also the only students who were able to make valid conclusions regarding the application of experimental results to Amanda's theory.

5. The results of the study indicate no gender differences with respect to the nature of science in the grade six students involved in the study.

Results of the NSKSE show males and females performing at similar levels. Also, no gender differences emerged from the interviews.

6. The results of the interviews support the position that the NSKSE was effective at discriminating between grade six students on the basis of their understanding of the nature of science.

Interview results from this study indicate that students who scored at the low end of the continuum on the NSKSE (55–61) did, in fact, have poorly developed views of the nature of science. The low-scoring students were unable to explain how science was creative, developmental, or testable. These students scored only marginally above the midpoint on the NSKSE and their interview results were indicative of students who were not confident in discussing issues related to the nature of science. Students who had high scores on the NSKSE (74–79) described science in ways that were consistent with the three-factor model of science on which the NSKSE was based. These students had a more developed understanding of the nature of science. For example, they understood that scientists create theories to explain physical phenomena (creative factor). They understood that scientific experiments were tests of theories and that the results of these tests were the basis of evaluating the theories (testable factor), and that this process of constructing and testing theories can result in scientific theories being replaced or discarded (developmental factor). Students HFB and HMB, both with scores of 68, articulated positions between the two extremes. Thus the interview results support the position that the NSKSE was able to differentiate between students' on the basis of their understanding of the nature of science.

However, even the highest-scoring students indicated that this process contributed to the ultimate goal of science—the creation of scientific knowledge that was absolute. This is consistent with the literature that contends that the move to relativism begins in late adolescence or early adulthood.

The next chapter presents a discussion of these findings and draws implications from this study.

CHAPTER 5

DISCUSSION OF FINDINGS AND IMPLICATIONS

Introduction

Current science education reform focuses on the goal of scientific literacy. One of the major sub-goals of scientific literacy is the development of students' understanding of the nature of science. While there are several rationales for the development of students' understanding of the nature of science, the two most common are the democratic argument and the science learning argument. The democratic argument contends that a participatory democracy requires a citizenry that can engage in debate and discourse about public policy. Many of the public policy decisions confronting society have a significant science and/or technology component. Therefore, understanding what science is about, how the work of science is done, and how knowledge claims are evaluated in science are required attributes for reasoned participation in a broad range of topics including cloning, genetically modified foods, nuclear power production, and waste disposal. The science learning argument contends that understanding the nature of science is a significant aspect of another major sub-goal of science literacy, having students construct and understand many of the major concepts and ideas of science. Several decades of research indicate that students' views of science are crucial factors in the reasoned acquisition of science concepts.

Curriculum developers, publishers, and teachers are engaged in creating science learning experiences that foster the development of views of the nature of science. Two main issues arise from that process. The first issue is the determination of what view of the nature of science is an appropriate one to foster in students. The second issue is the determination of what views of the nature of science students already hold. The literature indicates that there is no consensus regarding what view of the nature of science should be portrayed in the curriculum. Many within the field of science education argue for the explicit and exclusive portrayal of constructivist epistemology in science education. Conversely, many philosophers of science argue for either a balanced portrayal of realist and constructivist positions, or the portrayal of a common position with respect to the nature of science. This common position would constitute those aspects of the nature of science that both realists and constructivist agree are accurate reflections of the enterprise of science. The literature indicates that some writers on both sides are beginning to stake out this common ground.

The second issue identified was the determination of the views of the nature of science that students hold. This is important since more must be known about what views of the nature of science students hold and why they hold them, in order to effectively engage in this curriculum development task. The purpose of this research, therefore, was to investigate grade six students' understanding of the nature of science.

Research Questions

The questions that this research investigated were:

1. What range of positions do grade six students hold with respect to the nature of science and scientific knowledge?

2. Does gender or prior exposure to science curriculum affect the epistemological positions held by grade six students?

Discussion of Findings and Implications

1. The two highest-scoring students articulated more developed views of the nature of science than previously described in the literature.

The achievement of scientific literacy requires that students develop a sound understanding of the nature of science in order to evaluate knowledge claims (Giere, 1991; Hurd, 1997; Leach et al., 1997) and therefore construct or agree with the accepted scientific explanation for phenomena (AAAS, 1989, 1993; CMEC, 1997; Leach et al., 1997). While the literature indicates that elementary school students do not have a sufficient understanding of the nature of science to evaluate knowledge claims (Carey et al., 1989; Kuhn, 1993; Solomon et al., 1994), the current research suggests that some elementary school students are capable of achieving this level of understanding.

The views expressed by HMA and HFA went beyond those previously reported in the research for students this age and compare favorably with views of the nature of science reported in studies involving secondary students. The two highest-scoring students indicated that one of the main functions of science was the generation and testing of explanations for physical phenomena. They distinguished between descriptions of a phenomenon and explanations for that phenomenon. They differentiated between theories and experiments, and articulated a sound knowledge of science processes. They indicated that scientists created predictions based on some prior knowledge or understanding, that experiments were designed to be tests of theories, and that predictions generated by the theories were key aspects of this process.

The results from this research indicate that some children and young adolescents are capable of achieving many of the epistemological positions that the literature assumes can occur only in late adolescence. Although few studies have investigated children's understanding of the nature of science, the fact that views similar to HMA and HFA have not been reported elsewhere may suggest that current science curricula have not been effective in developing students' understanding of the nature of science.

Implications

Students who are able to evaluate knowledge claims in science in a manner that approximates that of practicing scientists are more likely to construct or accept the same explanations for phenomena that scientists do. Students who are unable to evaluate knowledge claims in science will either retain their naïve concepts or accept knowledge claims on the basis of authority. Neither of these two outcomes is compatible with the achievement of science literacy (Driver et al., 1996). The results of this study indicate that many of the views of the nature of science required for the achievement of scientific literacy are attainable in some elementary school students.

The level of understanding of the nature of science articulated by the high-scoring students from School A is encouraging, however, more research is required to confirm that elementary school students are capable of evaluating knowledge claims. As well, research must be carried out to determine which factors correlate with development of elementary school students' views of the nature of science. Once the factors relating to the development of students' understanding of the nature of science have been identified, the task of developing, implementing, and assessing a curriculum that supports this development can begin. The curriculum development and implementation activity currently underway is not grounded in a research base sufficient to inform this process.

While there is some evidence in the current research to suggest that holding a valid understanding of the nature of science correlates with students' ability to make valid theory choices in science, until now, there has been little research to support the relationship. Until such research has been conducted, the relationship between understanding the nature of science and theory choice in students remains an assumption.

2. The highest-scoring students were able to successfully evaluate a scientific theory in light of empirical evidence that they had generated.

While the majority of students interviewed did not successfully apply experimental results to evaluate Amanda's theory, the two highest scoring students did so. These results dispute research suggesting that children and young adolescents do not demonstrate the logic and metacognitive processes required to evaluate knowledge claims in science.

Implications

The literature indicates that students enter science classrooms with pre-existing explanations for many physical phenomena (Erickson, 1979; Saunders, 1993). Often these naïve explanations are at odds with the publicly accepted scientific explanations. In order to have students reject their naïve concepts in favour of the publicly accepted scientific explanations, students must be shown the reasons that the scientific theory is preferable to their own explanation. However, if students do not understand the nature and purpose of science, they will not be able to evaluate scientific theories in the same manner as scientists (Driver, 1989). For example, if a student is presented with data or observations supporting one theory over another, this information only constitutes evidence when viewed through an understanding of the nature of science and with an appreciation of why that particular evidence supports one theory and not the other. Contrary to the literature, the current research suggests that some grade six students are capable of making valid theory choice decisions.

If students are unable to make valid theory choice decisions they will either retain their naïve concepts or be forced to accept scientific theories presented by the teacher or text on the basis of authority. In either case, the goals of scientific literacy cannot be achieved. There are two reasons for this. If students retain their naïve concepts they will not understand and accept the scientific explanations for phenomena. Thus, they will not have achieved the science learning aspect of scientific literacy. When students retain their naïve concepts, they also do not develop an understanding of the nature of science that allows them to evaluate knowledge claims from science, thus failing to achieve the democratic aspect of scientific literacy.

The literature indicates that students who attempt to accept on the basis of authority those scientific theories and explanations presented by the teacher or text are often not successful at achieving a meaningful and useful understanding of these concepts. If the student does "learn" the explanation or idea without addressing their naïve concepts, the scientific concept is often compartmentalized and only used in science classroom contexts (Applelton, 1993). Thus, these students do not truly achieve the science learning aspect of scientific literacy. Since they have embraced an authority-based rationale for scientific decision making, they have also failed to achieve the democratic aspect of scientific literacy.

The current research suggests that the construction and/or acceptance of scientific concepts on the basis of empirical evidence and an understanding of the nature of science may be achieved, at least by some students, before the end of elementary school.

3. All eight students involved in the study held realist views of scientific knowledge.

Although the students interviewed in this study held a variety of views regarding the nature of science, all subjects indicated that scientific theories could eventually be determined to be true or false. This result is interesting in light of the fact that some of the students in the current study held more developed views of the nature of science than presently portrayed in the literature.

Implications

All of the students interviewed held realist ontological positions. Since even the highest-scoring students held absolutist views, this result supports the position in the literature that children and young adolescents are still in a dualistic stage of thinking. While HFA and HMA both agreed that science involved creativity, they indicated that the creativity and imagination were used in discovering an ontological reality.

Some constructivist researchers have equated more developed understandings of the nature of science with more relativist epistemological positions, to the point of naming more developed views as constructivist and less-developed views as objectivist. This position appears to be based on the assumption or opinion that constructivist epistemology is more preferable or defensible than one based on realism. Although the two highest scoring students, HMA and HFA, had well-developed views of the nature of science, they were realists with respect to ontology. The fact that grade six students with highly-developed views of the nature of science were realists suggests that a well-developed understanding of the nature of science is not incompatible with realist ontological positions in children and supports the view that realism be the stated or *de facto* ontological position in elementary school science curricula.

Given the constructivist-based approach of the curriculum at School A, this also suggests that constructivist pedagogy and realist ontology are not incompatible for students this age.

4. Students from School A, which has a history of extensive science curriculum and teacher professional development, demonstrated more sophisticated positions with respect to understanding the nature of science, than did their peers from School B.

Results of this study indicate that students from School A scored significantly higher on the NSKSE than their peers from School B who received a traditional science curriculum. Interviews results indicated that there were few, if any, differences between low-scoring students from the two schools, however, views of the nature of science held by the highest-scoring students' from School A were substantially more developed than the highest-scoring students from School B. Results also indicated that those features of the nature of science featured in the project school science curriculum were reflected in students' views of the nature of science.

While students from School A scored higher on the NSKSE on the creative subscale, testable subscale, and NSKSE overall, than their counterparts from School B, there was no significant difference between the two with respect to the developmental factor. One explanation for this is that at School A, students were often engaged in open-ended science activities designed to have them explore and investigate (Elementary Science Study, 1970). These tasks consistently placed students in the position of creating explanations for the physical phenomena under investigation (NSDEC, 1995; Schoenberger, 1995). These students were also frequently required to design and perform experiments to evaluate their explanations. Observations and data received from these experiments were used to evaluate the generated explanations. Thus the scores received on the creative and testable subscales may be attributed to prior science curriculum experiences.

The developmental subscale measures whether or not students agreed with the position that the accepted scientific explanation (the right answer) is subject to review and revision on the basis of new information or new interpretation of existing information. However, students at School A were not exposed to science curriculum that identified a particular scientific explanation as having this accepted status. In their science classes, closure and the acceptance of the publicly accepted explanation for a phenomenon was not discussed. Students who could defend their positions on the basis of evidence and a sound rationale were not told that their explanations were right or wrong. However, students were often asked to indicate the degree of confidence that they had in their theory and what sort of evidence would increase that confidence (NSDEC, 1995; Schoenberger, 1995). Thus students were not exposed to a science curriculum in which a particular scientific explanation evolved over time. Rather they were exposed to experiences where competing explanations were evaluated at the same time, but no explanation was ever granted the status of being publicly accepted. Since no theory was ever given an "accepted" status, this may explain why students from School A scored similar to their peers on the developmental subscale.

At the other end of the spectrum were the relatively poor results of the low-scoring students from School A. These students showed little or no understanding of the nature of science and were virtually indistinguishable from their low-scoring counterparts from School B. Given that School A had what was considered to be a model curriculum and exemplary implementation (NSDEC, 1995), this was an unexpected result. One possible explanation for this is that the high-scoring students were developmentally advanced for their age and thus were able to gain a benefit from their curriculum experiences that others could not. Stated in the negative, it may be that the poorly developed views of the nature of science expressed by the low-scoring students from School A may indicate they were developmentally unready for anything beyond authoritative knowledge justification. If this is the case, then the activities involving the production and evaluation of explanations for physical phenomena may have been an exercise in futility for these students. An alternative explanation is offered by Windschitl and Andre (1998), who conclude that there is an interaction between students' epistemological beliefs and the classroom learning environment, with individuals having more sophisticated epistemological positions learning more in a constructivist environment and students with less developed epistemological beliefs learning more with an objectivist treatment. The case of the low-scoring students from School A may represent a case of poorly developed understanding of the nature of science, coupled with a constructivist environment. Thus the results of the low-scoring students from School A may be a result of learning orientation, rather than developmental readiness.

The current study suggests that science curriculum may be related to more developed views of the nature of science in elementary school students. However, not all students benefit equally from their experiences. Research confirming this inequity and investigating its causes will assist greatly in our understanding of this process.

Implications

The current research suggests that elementary science curricula whose focus involves primarily science content and concepts, to the exclusion of science process skills and the nature of science, are not likely to be successful. Conversely, elementary science curricula that focus on the creative and empirical aspects of science and on the development of students' science process skills science in the context of hands-on, open-ended, science investigations may be related to development of students' understanding of the nature of science. This nature of science/science process skill focus should assist in the achievement of scientific literacy by equipping students to deal with their naïve concepts and enable them to make reasoned science theory choice decisions involving empirical evidence.

Closure, the acceptance of the publicly accepted scientific decision, was not a feature of the science curriculum at the project school. This suggests that "right answer" science curricula may conflict with development of students' understanding of the nature of science at elementary grade levels. The current results also suggest that each of the particular aspects of science that students are to develop must be explicitly represented and addressed in the curriculum if students are to move closer to these views.

Dr. Mary Schoenberger (1995) developed the scope and sequence for the curriculum involved in the elementary science initiative. The program combined the use of specific SAPA (Science: A Process Approach) modules to develop students' science process skills and the ESS (Elementary Science Study) curriculum's open-ended investigations (ESS, 1970). Given that the epistemological sophistication of the high-scoring students from School A, this reflects positively on both the SAPA and ESS curricula and on the elementary science curriculum scope and sequence designed by Dr. Schoenberger and implemented in the project school.

Since the high-scoring students from School A showed a more sophisticated positions regarding the nature of science than previously documented in the literature, the current research also supports the position that students' understanding of the nature of science is stunted by current science education practices.

The success of the students at School A stands in contrast with the lack of success of the curriculum initiative in the Meichtry (1992) study. While the difference between these results may be partially attributed to curriculum, several researchers (Lederman 1986; Yager 1966; Zeidler & Lederman, 1989) have concluded that teacher behavior is crucial to developing students' understanding of the nature of science. Thus the positive results of the students at School A supports the position that the nature and extent of teacher in-servicing in the elementary science initiative was successful in modifying teacher behavior and related to the project's success. The results of the current study reaffirm the importance of significant professional development opportunities in support of curriculum innovation.

This research has demonstrated that grade six students hold a variety of views regarding the nature of science. This variety has serious implications for science curricula. The science learning argument contends that students possess different epistemological frameworks, that these epistemological frameworks are involved in decisions regarding what explanations to accept and why they should be accepted, and that teachers should develop students' understanding of the nature of science so that they will be able to make theory choice decisions in favour of the publicly accepted scientific explanations, thus acquiring these concepts on the basis of reason rather than authority. However, it is recognized that the variance in students' epistemological positions means that evidence that is compelling to one student may not be for another. Similarly, it may be inferred from this study that learning experiences related to significant development in some students' epistemological positions do not cause similar advances in other students.

5. The results of the study indicate no gender differences with respect to the nature of science in the grade six students involved in the study.

Based on the results of the t-test for independent samples (see Tables 4–6), no significant differences were found between males and females on any of the subscales or on the NSKSE in this study. This held for each school individually as well as for the combined data. Likewise, no gender patterns emerged from the analysis of the transcripts. This result is consistent with previous research that shows no gender-related trends with respect to students' understanding of the nature of science in elementary (Adamson et al., 1998), junior high school (Levin et al., 1991) or high school students (Jungwirth, 1970).

Implications

The results of this study could simply be an indication that gender differences relating to views of the nature of science emerge after elementary school. Conversely, there may simply be no gender trends in individuals' understanding of the nature of science to be reflected. Although no gender differences were found in this study, gender differences remain an area for further research.

6. The results of the interviews support the position that the NSKSE was effective at discriminating between grade six students on the basis of their understanding of the nature of science.

While previous research (Aikenhead, et al., 1987; Lederman & O'Malley, 1990) has raised concerns regarding the ability of paper and pencil instruments to accurately assess students' understanding of the nature of science, interview results from the current study indicated that NSKSE results correlated with students' understanding of the nature of science. Students with the highest scores on the NSKSE articulated well-developed views of the nature of science. Students with the lowest scores articulated almost no understanding of the nature of science. Students whose NSKSE scores were between the two extremes articulated views of the nature of science between the lowest and highest scoring students. It should be noted that the lowest scoring students scored only marginally above the midpoint on the NSKSE.

Implications

While the NSKSE appears to have successfully predicted grade six students' understanding of the nature of science, it did not distinguish between individuals' ontological positions. Some researchers have equated a poorly developed understanding of the nature of science with a realist ontology and a well developed understanding of the nature of science with a constructivist position. The current research disputes this assumption.

Students with NSKSE scores close to the midpoint were also students who understood very little about the nature of science. Students with high scores also had well-developed views of the nature of science. However, given that all of the students surveyed scored above the midpoint on the NSKSE, no conclusions can be drawn about the ability of the device to successfully predict the positions of individuals who disagree with the three-factor model of the nature of science.

While the NSKSE was generally able to predict students' understanding of the nature of science, the comparisons used in this determination were limited to a small number of students selected because they had extreme scores on the device. Further research examining the relationship between students' views of the nature of science and NSKSE scores across a greater range of subjects is required.

Conclusions

The results of this study indicate that the range of views of the nature of science held by grade six students is greater than had been indicated in the literature. Specifically, two students in this study expressed positions regarding the nature of science that were more developed than previous studies had documented. These two students indicated that one of the main functions of science was the generation and testing of explanations for physical phenomena. They distinguished between descriptions of a phenomenon and explanations for that phenomenon. They differentiated between theories and experiments, and articulated a sound knowledge of science processes. They indicated that scientists created predictions based on some prior knowledge or understanding. They indicated that the experiments were designed to be tests of theories, and that predictions generated by the theories were key aspects of this process. They also successfully applied experimental evidence to evaluate a theory.

Results from the study suggest that constructivist-based science education experiences may be related to the development of grade six students' understanding of the nature of science, however, not all students accrue the same benefits from their learning experiences. All of the students interviewed, including those with the most developed views of the nature of science, held realist ontological positions. This result disputes the position of some researchers that more developed views of the nature of science are related to constructivist (relativist) epistemological and ontological positions. No gender differences were found in either the survey or interview portions of the study.

The results of the current study differ from the findings in the literature. These differences may be attributed to two factors. The first is that those students whose views were more developed than previously reported had experienced a model science curriculum. The second is that the study deliberately attempted to explore the range of positions held, rather than trying to describe grade six students' understanding of the nature of science in general.

Further areas of research identified by this study include investigating the development of elementary school students' understanding of the nature of science and identification of the factors related to such development, determining if a valid understanding of the nature of science is related to students' ability to make valid theory choices in science, verification of the range of positions demonstrated in this research, and investigation of the relationship between students' understanding of the nature of science and patterns of learning and teaching in elementary science classrooms.

Appendix 1

NSKSE

1. The knowledge that we get from science is a result of human imagination. [creative+]
2. The knowledge that we get from science does not change. [developmental-]
3. Before we accept a scientific idea or explanation we must be able to test it. [testable+]
4. The knowledge that we get from science is discovered, not created by people. [creative -]
5. The knowledge that we get from science can be reviewed and changed. [developmental +]
6. The knowledge that we get from science can be accepted even if there is no evidence to back it up. [testable-]
7. A scientist is like an artist because they both need to think creatively. [creative+]
8. The knowledge that we get from science today will always be accepted as true. [developmental-]
9. Knowledge that one scientist produces will be accepted if the evidence for it can be repeated by other scientists. [testable+]
10. The knowledge that we get from science is not a result of human imagination. [creative -]
11. The knowledge that we get from science is uncertain. [developmental+]
12. We can accept knowledge that we get from science even if there is no way that we can test it. [testable-]
13. Ideas and explanations from science, such as laws and theories, show creativity on the part of the scientist. [creative+]
14. The knowledge that we get from science is certain because experiments are repeated until the scientist gets the right answer. [developmental-]
15. Before we accept knowledge from science we must get reliable (consistent) results supporting it. [testable+]
16. Ideas and explanations from science, such as laws and theories, do not show creativity on the part of scientists. [creative-]
17. The ideas and explanations that scientists accept today may have to be changed if we learn more. [developmental+]
18. If a scientist does not share his or her evidence then other scientists will still accept the idea or explanation. [testable-]

Appendix 2

NATURE OF SCIENTIFIC KNOWLEDGE SCALE—ELEMENTARY

Student Register #_________School____________________ Date_______

Item Number	Strongly Agree	Agree	Unsure	Disagree	Strongly Disagree
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					

Comments

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Appendix 3

The following section presents the interview protocol in bold type and the explanation relating that item to the nature of science and the nature of scientific knowledge in italics.

Interview Protocol

Amanda has a theory about oils. She believes that some oils are thicker or thinner than others and that this makes the oils behave differently. She also believes that thicker (heavier) oils will be darker than thinner (lighter) oils.

Question 1
Do you believe her theory? Yes/No/No reason to believe or disbelieve
Why do you believe/not believe it to be true?
If "no reason to believe or not believe" ask "Can you think of any evidence which would support or contradict her theory?"

This question asked students to make a personal decision regarding their belief in the theory, and then investigated the justification for that belief. This allowed an examination of the issue of evidence and the linkage between empirical evidence and scientific knowledge. Students were asked later in the protocol about the distinction between believing in a theory and that theory being "true."

This set of questions related to the developmental and testable aspects of science. If a student began to discuss the theory as being true or untrue it may have indicated an epistemological position that contradicts the developmental aspect of the three-factor model because it may have implied that scientific knowledge is absolute and predetermined. Also, if the student indicated that they believe the theory is true but could supply no supporting evidence it contradicted the testable aspect of the model. These issues were dealt with more specifically later in the protocol.

Question 2
What is a theory?

This question set the stage for later questions involving students' understanding of theories. This provided the first opportunity to discuss the origin of theories and whether they are created by scientists or predetermined. Thus this question dealt with the creative aspect of science.

Scientists also create theories.
Question 3
Why do scientists create theories? OR What is the purpose of a theory?

This was a follow up to the previous question. How the question was posed was determined to some extent by how they answered the previous two questions. This question dealt with the origin of theories and whether they are created or discovered. Therefore it had important implications for the creative aspect of science. This question also addressed the role of theories as potential explanations for physical *phenomena and the relationship between theories and experiments which are intended to be tests of the theory. Therefore, this question also addressed the developmental and testable aspects of science.*

Once a theory is created, scientists usually try to test it.

Question 4
How do scientists test theories? OR What is an experiment?

If the student did not refer to testing or experimentation in the discussion of the previous question this section introduced it. This question investigated students' understanding of the role of experiments as tests of theories. Therefore, it related to the developmental and testable aspects of science.

Often scientists make predictions before they do experiments.

Question 5
How do scientists decide what predictions to make?

This question helped examine students' understanding of the role of experiments as being created to test theories. Therefore, this question dealt with both the creative and testable aspects of science. Students had the opportunity to discuss where they thought theories and prediction came from. It investigated the role of creativity in the generation of theories and the role of the scientist as the individual who has created the theory and invented or created a means of testing it.

Question 6
Why are these predictions important?

Similar to the previous question, this question related to the testable and creative aspects of science. It dealt with understanding that a prediction is based on a specific theory and that the experiment is created and structured to be a test of the predictive ability of the theory.

Question 7
Which of these statements best describes what happens to a theory after it is tested?
(a) The results of the test/experiment will increase/decrease the scientist's confidence in the theory.
(b) The results of the test/experiment will prove the theory to be true or false.
  If (a): Can a scientist be more sure of some theories than others?
  If (b): What does it mean when a theory is true?

This question related directly to the student's understanding of the nature of scientific knowledge. If the student believed that scientific knowledge is developmental then the response would indicate that experiments increase or decrease confidence in a theory or that they relate to the level of empirical support for it. Further questions with these students probed their understanding of the developmental aspect of science and the role of experiments in making decision about scientific explanations. For these *students this question related to both the developmental and testable factors.*

If a student chose answer B), that the theory is proven to be true or false, the next question probed their understanding of what it means for a theory to be true or false. Did it mean that it is true in the absolutist sense, or did this student's understanding of "scientific truth" allow for some changes and evolution in explanations and theories? If so, then the student still believed that scientific knowledge is developmental and changes over time. In either case the discussion then focused on the role of experiments and evidence in decision regarding scientific knowledge.

Question 8
Can scientists accept a theory even if it cannot be tested? OR Can scientists accept a theory even if there is no evidence to support it?
Why or why not?

The first question related directly to the testable factor of the model and expands upon previous questions that involved testability. Some students may have previously differentiated between a scientist accepting a theory and the enhanced status of the theory being "true." If so, this series of questions included asking the student if we can determine if a theory is "true" even if we have no supporting evidence or if there is no way to test it.

Question 9
Which of these is more important to the work that scientists do?
(a) creating theories and models? OR (b) making careful measurements?
Why?

Students who scored low on the creative factor would have been more likely to choose B), since they did not believe in the scientists' role as the creator of theories and/or explanations, but rather as "discovering" them. Regardless of which answer the student chose, follow up questions asked "why" they hold that view and allowed insight into both their understanding of the role of inventing models and theories (creative factor) and on taking careful measurements (testable factor).

Scientists often make models or diagrams to help clarify their thinking. In many cases the model represents parts that are too small to be seen. If Amanda thinks that different oils are thicker or thinner than others, and that darker oils are thicker than lighter oils, she should be able to draw a diagram (model) which shows why this might be so.

Question 10
Using your imagination, draw a diagram of the particles of light oil and dark oil which might help Amanda explain her theory. Briefly explain your diagram.

This question allowed students to create or invent explanations for the properties of oil. Students were asked to put into practice some of the activities and ideas that they *have previously discussed. This section was one in which school differences may become apparent. Students from School A have had more experience at creating and testing explanations and some differences between the two groups could emerge during the "Oily Peppercorns" activity.*

LIGHT OIL **DARK OIL**

One way that can be used to measure the thickness or heaviness of an oil is to measure how much time it takes for an object to fall through the oil. Scientists assume that objects or particles will take longer to fall to the bottom of heavier oils. Therefore, measuring the amount of time it takes for an object to fall through the oil can be used as a measure of its thickness.

Question 11
Is it alright for scientists to make assumptions when they do an experiment?
Why or why not?
If "Yes" ask Is it possible for a scientist to do an experiment without making some assumptions?
Why or why not?

A "No" answer to this question would be an indication that students either have an absolutist view of scientific knowledge or see scientific knowledge as being unproblematic. School differences could be involved in this question as well.

OILY PEPPERCORNS
On the table in front of you are three bottles. Each bottle contains a different type of oil. You should have a supply of peppercorns and a stopwatch.

Purpose
Using the stopwatch, you are to measure the time it takes for peppercorns to

travel through the three different types of oil.

Procedure

Drop a peppercorn into the corn oil. Start the watch when the peppercorn reaches the top black line and stop the watch when it reaches the bottom black line. Record the time on the data table provided. If the peppercorn floats simply ignore it and try another one. Leave the peppercorns in the container when you are finished.

	Corn oil	**Sunflower Oil**	**Canola Oil**
Trial #1			
Trial #2			
Trial #3			
Trial #4			
Trial #5			

Repeat this procedure 4 more times for the corn oil.
Repeat the entire procedure for the other two oils.

Question 12

Name two variables (conditions or factors) that were controlled (kept the same) in this experiment.

This question examined the student's understanding of experimental procedure and controlling of variables.

Question 13

Identify one or two sources of error that would explain differences in the times recorded in this experiment.
Explain how you think these two sources affected the times recorded.

In the Oily Peppercorns activity there was tremendous variability in the peppercorns used, resulting in unreliable data. This question laid the groundwork for addressing the issue of uncontrolled variables or other possible explanations for the variability in results.

Question 14

Based on the data that you have collected, can you decide which of these three

oils is the thickest and which is the thinnest?
Explain your answer.
If "Yes" ask,
Which is the thickest oil?
What evidence do you have to support that? OR How do you know that?
Which is the thinnest oil?
What evidence do you have to support that? OR How do you know that?

This question asked students to apply the principles that they have previously discussed and interpret experimental results of data that they have received. The follow up questions dealt with the relationship between the conclusions (rankings) and the supporting evidence. This question and the following one allowed an examination of the student's epistemology in action and a subsequent comparison to their espoused epistemology.

Question 15
Was Amanda's theory supported by the evidence?
Does that make it correct?
Why do you think that?
Do you have any other explanations for the data? OR Do you have any other theories to explain the results?

This question drew together the student's interpretation of the results and their understanding of the nature of science and scientific knowledge. The student will have applied the experimental findings to Amanda's theory and evaluate the theory in light of this evidence. This question related directly to the developmental and testable factors.

Question 16
Sometimes we replace one part of as theory with another and sometimes we replace the entire theory with a new one. Why do you think that this happens?

This question built on earlier specific questions and asked students to discuss the general principles of theory choice in science. This topic encompassed all three aspects of the model.

Question 17
Sometimes a group of scientists disagree over whether or not to believe a particular scientific theory. How can this happen?
What sort of things would cause this disagreement?
If a group of scientists had the same results from the same experiments could they still disagree about what the results meant?

This question dealt with theory choice in science and the factors that go into decisions about acceptance of theories. It dealt explicitly with the developmental *factor and to some extent with relative and interpretive nature of knowledge.*

Question 18
If two different theories seem equally "good" at explaining something, how do scientists decide which theory is better?

This was a continuation or extension of the previous series of questions and also dealt with theory choice and the possibility of differing but justifiable positions.

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