HIGH SCHOOL STUDENTS' VIEWS OF THE NATURE OF SCIENCE

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High School Students' Views of the Nature of Science

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For the past year and a half this thesis has consumed most of my time and creative energy. During the entire time, from the original conception of the idea of this project right up until the date of final submission, my supervisor, Dr. Alan K. Griffiths has been a source continual support and encouragement. The many hours he has spend assisting me with this thesis, coupled with his high standards of expectation have resulted in what has been for me the most satisfying project I have ever undertaken. I owe him a great debt of gratitude.

I also owe my wife Josephine a similar debt for her support and patience.

Abstract

This study examined high school students' views of the nature of science. A stratified random sample of 32 students chosen from nine schools in eastern and central Newfoundland were interviewed on an individual basis. The interviews were semi-structured and were administered in general accordance with an interview guide. The transcripts were reduced to a set of individualized conceptual inventories. The frequency of occurrence of each representative statement was tallied and tabulated. A number of general trends were identified. Most students were found to have difficulty establishing the domain of science although many tended to view the practice of science as cumulative. Although the majority of the sample asserted that scientific information was tentative and provisional, they tended to regard factual information in science to be absolute and irrefutable. Scientific theories appeared to be only understood in a naive sense in that most subjects regarded theories as suggested explanations for fairly discrete events as opposed to elaborate interpretive frameworks. In accordance with previously documented evidence (Aikenhead, 1987) many subjects were found to

equate the term "scientific law" with the more common legal usage of the word. Finally, elements of what Nadeau and Desautels (1984) term as naive realism, blissful empiricism, credulous experimentalism and excessive rationalism were found to be quite prevalent in the transcripts.

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CHAPTER 1

The Problem

Introduction

It is generally agreed that the promotion of consistent and mature views of the nature of science is a valid goal of science education. Indeed in its Report 36 (1984), the Science Council of Canada stressed the importance of this objective. Studies by Orpwood and Alam (1984) and by Orpwood and Souque (1984) however, indicate that practice does not coincide well with intent. These studies showed that many Canadian teachers do not regard the nature of science as important and that they place much more emphasis on enabling students to learn the various concepts associated with science than they do on developing concepts of the nature of science. Orpwood and Alam (1984) reported that many curriculum materials in use in Canadian schools indicate a lack of emphasis on the nature of science. It has been pointed out (Robinson, 1969) that many science curricula are not founded on sound or consistent ideas in the philosophy of science. Despite the great volume of literature available on the philosophy of science, educators have been reluctant to apply the more mature and sound views to new curricula.

According to Robinson (1969) and Summers (1982), teachers as well as students should understand the nature of science. In fact, Scheffler (1973) states that it is even more critical that science teachers have well developed conceptions of the nature of science than it is for scientists and other normal practitioners of science. Similarly, Robinson and Summers argue that teachers, as professionals, should know what it is they do and how they do it. Both Robinson and Summers further suggest that teachers' conceptions of what it is they are doing may influence the way in which they teach. Unfortunately as has been pointed out by Ogunniyi and Pella (1980), Rowell & Cawthron (1982), Bileh & Malik (1977), these views may be of a rather naive nature. Nadeau and Desautels (1984), who criticized much teaching as contributing to a unrealistic view of science, state that scientism is, in fact, reinforced by teachers who pay insufficient attention to the nature of science. Nadeau and Desautels note five separate unacceptable views of science that may exist in the minds of teachers and students:

Naive Realism: The belief that scientific knowledge is an exact reflection of things as they really are, that science furnishes us with a set of facts that correctly and faithfully describe reality.

Blissful Empiricism: The belief that all scientific knowledge arises directly and exclusively from observation of phenomena. In this view the practice of science is basically seen as the relentless gathering of observational data which will point singularly, objectively and conclusively to the truth.

Credulous Experimentalism: The belief that experimentation makes possible the conclusive verification of hypotheses. This view sees experimentation as an objective and completely trustworthy resolver of difficulty within the scientific world.

Blind Idealism: The belief that the scientist is a completely disinterested, objective being. This view quite effectively embodies within every scientist, the image of the perfect scholar of science while remaining all too oblivious of his or her human nature.

Excessive Rationalism: The belief that science brings us gradually closer to the truth. In this view, the practice of science over the centuries has been cumulative and as time proceeds, more and more knowledge is being uncovered as mankind marches steadily onwards in quest of the ultimate truth.

It is possible that the existence of such views may be reinforced by teachers who, themselves, hold similar views of science. This view is expanded upon by Duschl (1985, 1988) who notes that current science education programs, as well as the teachers themselves, tend to promote many of these inaccurate beliefs. Duschl makes a strong case for a major attempt to bring the philosophical underpinnings of current science programs more in line with current philosophy and views of the nature of science; views which, in recent years, have matured and become more generally acceptable. According to Duschl, scientism will prevail until others such as historians and philosophers are involved in the construction of science curricula.

Some Views of the Nature of Science

How science progresses.

Little agreement appears to exist about the answer to the question **"What is the Nature of Science?"** A reading of philosophers such as Kuhn, Popper, Lakatos and Feyerabend only serves to make this point painfully clear. Disagreement exists about even the most fundamental assumptions of the scientific enterprise. Some writers, such as Popper (1959), assert that it is essentially a rational process while others, such as Kuhn (1962), postulate that the fundamental cause of change in scientific thinking is predominantly social.

Possibly the most simplistic view of science is one which may be termed naive inductivist. According to this view, science is seen as something which is based on experience. Information thus obtained is assumed to have arisen from a number of impartial and unbiased observations by objective individuals. It is further assumed that these observations have occurred with sufficient frequency to attract the attention of the persons involved. Universal laws, which may be used to predict future events, may arise as generalizations are made from many observations. In this view, the emphasis is on prediction of future behavior with a typical situation involving a scientist, after studying a number of behaviors in some system, generalizing this behavior to events outside the system. That is not to say that the naive inductivist considers explanation irrelevant--in some instances explanation can play a significant part. For the inductivist, explanation would also arise from generalizations from series of observations. The naive inductivist assumes that the practitioners of science are detached in the sense that they do not let personal opinions and feelings conflict with their investigations. The practice of science is therefore viewed as the constant gathering of observational data and the repetition of experiments in order to build up a data base sufficient for generalization. In this view, science is basically an additive process which advances as more and more observations accumulate.

An alternative viewpoint to the above, one which may be termed <u>falsificationist</u>, suggests that science progresses as poor theories are replaced by more adequate ones. The acceptability of all statements depends upon their ability to withstand testing. Good theories must therefore be falsifiable. In fact, as a highly falsifiable theory would be broadly applicable with few restrictions, it is to be preferred over more limited theories. Much work in science therefore consists of finding the shortcomings in current theories and remediating the deficiencies either by modifying the current theory or by developing completely new ones. Science is therefore seen to proceed along a more or less rational course. As a problem emerges, a wide variety of explanations are posed. These explanations will range from minor modifications to current theory to broadly speculative--even bizarre--statements. Problems will be quickly identified with many of these statements and they must be rejected. In time, only a few of the original statements will remain and the previous problems will have been remedied. However, new problems will occur and the process repeats along different lines of enquiry. As the possibility always exists that theories may be found deficient, they must always be regarded as tentative. A more sophisticated falsificationist view also allows for the existence of multiple theories.

Both the naive inductivist and the falsificationist views place importance on the objectivity of observation; that different observers, when viewing the same event, will interpret it in the same way. For the naive inductivist, it is the objectivity of observation which guarantees that many mutually agreeable events are seen and recognized. For the falsificationist, as observation is often used to refute theory, it must be trusted. This belief, however, is open to question. One finds that it is impossible to make an observation statement without making at least some use of the terms, conditions or variables defined previously in some theoretical framework. For example, suppose that a student was to make an observation statement after observing the behavior of two magnets which had been laid, unbeknownst to him, in such a way that the like poles were in close conjunction with one another. A very simple such statement would be "the magnets repelled." If one analyzes this seemingly neutral statement, it may be seen that the statement can only be understood within a theoretical framework which presupposes that magnets exist, that there is such an entity as a force, that objects can apply such an entity on one another through some distance and finally that this entity results in some motion which can be observed.

In this way, then, it would be naive to assume that any observation, duly recorded, could ever be legitimately regarded as objective. In fact it is clear that, the more precise the observation statement, the more precise the use of theory. Observation statements, then, can only be understood within the theoretical framework used by the observer and hence may not be regarded as objective. Being grounded in theory then, these observation statements must only be considered as secure as the theory in which they are to be interpreted. The naive inductivist, who uses observation as the basis for future work, is therefore placed in a difficult position. If observation data can only be understood within the framework of existing theory then it cannot be true that observation is used to generate scientific knowledge and it can hardly be trusted to generate new theory. Likewise, the falsificationist, who relies on observation to falsify inadequate statements, is left somewhat disarmed and forced to contend with the fact that the observations may themselves be flawed.

A different view, postulated by Kuhn (1962), suggests that sociological factors are of more importance with respect to progress or change in science. Scientists attempting to flesh out the currently accepted paradigm are said to be practicing normal science. For those scientists, this paradigm, which is essentially the whole body of currently acceptable theories, definitions and operating procedures has been absorbed through practice and training. "Normal" scientists may find it difficult to express the accepted paradigm in a propositional manner but it is powerful in the sense that it bears up well under scrutiny, at least in its time. In Kuhn's view, practitioners of science are powerfully guided by the prevailing paradigm and tend not to assume it to be false when difficulties arise. Such difficulties are normally regarded as anomalies rather than contradictions. When important difficulties do become apparent, however, a crisis may develop. The process of normal science may, for a great many scientists, give way to a period of revolutionary science as a more acceptable paradigm is sought. When found, the acceptance of this paradigm may be based upon many factors, not necessarily deduction or proof of adequacy; some scientists may even decide to reject the new paradigm and continue working within the old one. In this way, science may be considered as something which does progress, but it is not necessarily the case that science progresses towards some universally accepted truth.

In another view, Lakatos (1974) sees science as consisting of research programs. To be considered scientific, these programs, which closely resemble Kuhn's paradigms, must have a coherent framework. According to Lakatos, two heuristics, the positive and the negative, determine respectively how science should proceed and what should not be rejected. The hard core of the program, the collection of statements and definitions which underlie it, is protected by the negative heuristic. Problems found with the program must be corrected by modifying the supporting statements surrounding the hard core. Scientists who decide to modify the hard core are making such fundamental changes that they are actually opting out of that research program. The work of scientists who choose to remain within the program is guided by the positive heuristic. This positive heuristic need not be well-defined. In fact Lakatos (1974) admits that it may only consist of partially articulated suggestions or hints on how to proceed and what to change.

Lakatos' use of research programs allows him to distinguish between scientific and non-scientific ones. To be considered scientific, programs must be consistent and able to survive without recourse to ad hoc additions and conditions. In this view, research programs can be considered as progressive if they appear to be stimulating new ideas and information. Those which are continually leading to difficulties which are not solvable within the accepted framework are considered degenerative.

A final view to be considered here stems from Feyerabend (1975), who sees science as something which can only be understood on an individual basis. The fundamental driving force behind science and scientists is different for each individual; the idea of one universally accepted scientific method makes little sense. According to Feyerabend the only conclusion possible about science is that it exists and has put in place mechanisms which guarantee that it will continue to do so. Thus the scientific enterprise is seen as a morass of individuals, each pursuing his or her own interests.

<u>The nature of scientific theories.</u>

Hodson (1982a,b) and Chalmers (1982) describe two views of the nature of scientific theories which they respectively label <u>realist</u> and <u>instrumentalist</u>. The realist approach assumes that the world exists independent of us. In this view more adequate and acceptable theories are considered as closer approximations of the "truth". Seen in this manner, the practice of science appears to be a process similar to that of completing a jigsaw puzzle. As time goes on and as more advancements are made one can better discern the true nature of the subject of the investigations. The dynamic nature of theories would therefore be seen as closer and closer approximations of truth with the final result being, hopefully, truth itself. This approach allows one to view theories as either true or false.

A fundamental problem with a strictly realistic view is that most theories deal with idealized situations. Many theories in physics, for example, deal with the behavior of particles and waves in certain, strictly specified conditions. These conditions, however, rarely occur naturally and are more often manifested along with a host of other circumstances. Although they do not normally occur, then, we assume that if they were present the behavior of the body in question would be correctly and accurately predicted or explained. This, in turn, leads to a sense of detachment from reality and therefore compromises the sense of realism.

According to the instrumentalist approach, theories would be seen as useful guides; as convenient fictions; as workable explanations of observed phenomena. The value of a theory would be measured against its usefulness. The theory is not required to actually represent phenomena as they exist. It is, instead, required to present a workable explanation which could be put to some good use. There is no direct link between observation statements and statements within the theory. The observation statements, more or less, are descriptive while the theoretical statements are usefully interpretive. Though they are derived from the observations, the theoretical statements need not make exact literal use of them. The theories are not intended to explain so much as to predict. Theories, however, often lead to novel predictions--ones of which the original proponents may have been unaware. In this way, many theories can be considered as having their own ontological existence. A strictly instrumentalist view has great difficulty in satisfactorily explaining this occurrence.

Another view, one which may be termed as <u>radical instrumentalism</u>, <u>pluralistic realism</u> or <u>unrepresentative realism</u> was presented by Chalmers (1982). According to Chalmers, no distinction is made between theoretical language and observational language. Chalmers further asserts that neither presents the world as it actually is. In presenting a somewhat unified combination of theoretical and observational language, Chalmers suggests that despite the fact that knowledge is to some extent derived from the external world, the contents of many of our ideas cannot be observed, although it is often useful to treat them as things which actually do exist. The very nature of the theories we hold depends on the way in which we view the world. If, for some reason, we change the way in which we view the world, the nature of acceptable scientific theories must also change as we would now view the world as consisting of somewhat different things. This view acknowledges the existence of reality and of the possibility of the existence of a realistic theory. It does not, however, require that the theory in question be regarded in a strictly realistic way in that the constructs used in it do not have to correspond directly with reality.

Nagel (1969) considers theories as general assumptions or instruments for use in scientific investigations. For him, theories basically function as interpretive frameworks and are mainly useful in that they allow the scientist to organize and interpret observational data. Nagel's description of theories includes three categories which correspond to scientific theories. Strategic variable theories, the simplest, merely list the relevant factors involved. These are low in complexity and are difficult to either confirm or refute as they make no behavior claims. Limited generalizations, the second type of theory, describe some measure of dependence between variables. As the name suggests, these theories are inductive in nature. Nagel termed the most complex type as integrated systems. These rely on inter-related and mutually compatible concepts. They may be quite extensive and have considerable ability to predict and explain events. It can be seen that Nagel's generally inductive views contrast somewhat with those of

Popper (1959). Popper, who is essentially a falsificationist, chooses to adopt a more deductive outlook towards the practice of science and of the testing of theories in particular. Like other falsificationists Popper asserts that theories are falsifiable but not verifiable. However he further states that the process is quite deductive in nature. Scientific laws, he states, are tested purely by deductive methods.

A different viewpoint was described by Penrose (1989) who distinguishes among three types of theory: <u>superb</u>, <u>useful</u> and <u>tentative</u>. Theories, in order to merit the title superb must be greatly applicable to the real world and must predict events with a very high degree of accuracy. Examples would include Newton's classical theory, Maxwell's electromagnetic theory and Einstein's general and special theories of relativity. Useful theories differ from superb theories mainly in that they have not been fully explored and that their predictive ability is considerably less, though still usable. Examples would include the Gell-Mann-Zweig quark model of hadrons and the big bang origin of the universe. The third category, tentative theories, differ mainly from the useful theories in that they lack significant experimental support. Some examples from this category would include superstring theories as well as the several grand unified theories (GUT's). It may be seen that Penrose's view is essentially instrumentalist in nature. He makes no clear distinction between theories and models, choosing even to include a few models--the so-called "standard model" for instance--as examples of theories. Penrose's conception of theory is systemic in nature. Rather than treating theories as suggested answers or explanations to specific problems he deals with theory as a unified system of concepts. The examples cited above, for instance, would be impossible to state in brief and only exist as a system of related and clearly defined concepts. In order to explain any of the theories mentioned one would essentially have to describe a fairly complete world view.

The nature of scientific knowledge.

At the extremes, one can adopt either a relativist or a rationalist orientation towards scientific knowledge. A relativist position would arise if it were understood that scientific knowledge can only be understood within its historical and social perspective; that there is no universal criterion on which to judge the merits of a particular piece of scientific information. According to this view it is not unreasonable, then, that different scientific communities would attach differing values to the same piece of information depending on its applicability to each individual situation. A certain fact or theory, which may be judged to be quite useful by one group, may not be beneficial or even accurate to another group. The rationalist, on the other hand, is more apt to believe in the existence of this universal criterion of value. Whereas relativists would have great difficulty in distinguishing between science and non-science, rationalists are capable of easily making the distinction by using this criterion as a guide.

Hodson (1982a,b) suggests another fundamental area of difference in perspective, noting that essentially there are three ways in which one can view the nature of scientific knowledge. The first is termed the subjectivist view. In it science is seen as a personal construction consisting of individual scientists each with his or her own beliefs and perspectives. Scientific knowledge is therefore unique to the individual concerned. The second, the objectivist view, sees scientific knowledge as something which exists independent of the scientists or the persons involved with it. This knowledge can sometimes lead to unintended effects and can result in situations of which the original proponents were unaware. The third view, the consensus view sees scientific knowledge as something which is accepted by and subservient to the community. Its value can be evaluated according to the extent to which it meets the community's needs.

Chalmers (1982) also presents a somewhat similar fundamental bifurcation of views. If one considers scientific knowledge in the way that it is understood by each individual, then it must be concluded that the extent of that knowledge much be broad indeed. Each individual likely interprets each piece of information in a way which is unique with more concepts being formed from simpler ones. If one wishes to arrive at the root or fundamental assumptions therefore, one may have to contend with the problem of infinite regress. If more complex ideas are built upon simpler ones and these in turn are built on ones even more simple then where does the process end? In order to deal with this problem one will have to either have to assume that the mind is in itself capable of constructing sense of the known universe and justify the <u>rationalist tradition</u> or instead assume that true information can only be created from sense data--observations--and justify the <u>classical empiricist tradition</u>.

One can, however, consider scientific knowledge in yet another way. Consider a fairly complex body of physical theory, say quantum mechanics. This body of information is such that it cannot be summarized briefly. It can only be understood within a complicated framework of supporting conditions, terms and observations. It is powerful to the extent that it can result in quite novel--even bizarre--predictions, and complex to the extent that many teams of scientists can view it and work with it in quite different ways. A view which only understands this body of information on an individual basis can easily be seen as inadequate. One would tend instead to ascribe to this body of information an individual character so that when several different people speak of "quantum mechanics" each knows that the other is speaking of a set body of knowledge, equally accessible to both. This is not to imply that both individuals must ascribe the exact same meaning to the theory. Two individuals may have different views of a third person. It must still be concluded that that third person still has his own individual existence even though that as perceived by the two outsiders may be different for the simple reason that both have likely had different experiences with that third person. In the same way we may associate with a theory its own individual existence although we need not expect all people to have the same interpretations of that existence.

Studying the Nature of Science

From time to time science curriculum researchers have been concerned with identifying students' understandings of the nature of scientific practice and of scientific knowledge. Methodologies have included the use of questionnaires (Barufaldi, Bethel & Lamb, 1977; Lamb, 1977; Rowell & Cawthron, 1982; Andersen, Harty & Samuel, 1986; Saunders, 1986), tests (Crumb, 1965; Trent, 1965; Kimball, 1967; Carey & Stauss, 1968; 1970; Mackay, 1971; Ogunniyi & Pella, 1980; Ogunniyi, 1982; 1983; Lederman, 1986a,b; Aikenhead, 1987; Aikenhead, Fleming & Ryan, 1987; Lederman & Zeidler, 1987) and interviews (George, 1987; Fleming, 1988; Lederman & O'Malley, 1990). It is generally agreed, however, that instruments developed have all been flawed in one way or another (Aikenhead, 1973; Doran, Guerin & Cavalieri, 1974; Lucas, 1975; Mayer, 1982; Aikenhead, Fleming & Ryan, 1987). One difficulty is associated with researchers' differing understanding of the nature of science. Another is the possibility of what Munby (1982) refers to as the doctrine of immaculate perception, the possibility that students may interpret test items erroneously or otherwise in different ways than was intended.

Few researchers have adopted an approach which has involved interviewing students about the nature of science and its products, despite the fact that science educators have been greatly pre-occupied with interviewing students about their understanding of a range of scientific concepts. Such research has uncovered a diversity of conceptual understandings and misunderstandings, and that students typically develop conceptual frameworks (Driver & Easley, 1978). It seems inevitable that this phenomenon will carry over into students' understanding of the nature of science itself. Despite the existence of such individual frameworks, students typically overlap with respect to particular misconceptions (Griffiths and Preston, in press). Further these misconceptions often display similarity across grade levels (Osborne & Cosgrove, 1983). Hence a well-defined approach to determining conceptions and misconceptions at one grade level may well be applicable at other levels. The present study was conceived with this in mind.

Purpose of the Study

The study attempted to obtain qualitative data relating to student views of science in order to further the understanding of what students are actually thinking rather than to see whether they are adequate in light of what the philosophers think. Rather than focusing substantially on the prevalence of the concepts, an attempt was made to highlight the diversity of views which exist. Finally an attempt was made to highlight specific instances in which those conceptions actually differ from accepted models.

Research Questions

The study focused on the following research questions:

1. a. How do students view science in general?
   b. How do students conceptualize change in science?
2. a. How do students believe scientific knowledge is obtained?
   b. What are students' conceptions of the nature of scientific knowledge?
3. a. What are students' conceptions of the nature of scientific theories?

b. What are students' conceptions of the function of scientific theories?

4. a. What are students' conceptions of the nature of scientific laws?

   b. What are students' conceptions of the function of scientific laws?

Delimitations of Study

It is necessary to delimit the findings of the study in several ways.

1. The study was limited to students in one particular age group. Specifically, the study focused on "level three" students in a number of schools of the Newfoundland and Labrador High School system. These students were in their last or last but one year of high school. Although, strictly speaking, results cannot be generalized to other groups, there is no reason to believe that similar results would not have been obtained for other groups.

2. As the concepts examined in this study are basically philosophical in nature and students need a certain amount of maturity to deal with them in a meaningful fashion, it was decided that studying a younger age group might produce random responses. Different results might be obtained with younger subjects.

3. Local geography also played a significant role in the selection of subjects for the study. As schools in the province of Newfoundland are widely separated, efficiency dictated that the sample had to be chosen from schools in a fairly small geographic area. Only students attending school in central and eastern Newfoundland were included in the study. It is possible that results are not generalizable beyond this group. However there is no reason to believe this group to be atypical of students in North America in general.

4. In addition all subjects were interviewed by the same investigator. As will be seen in chapter three, major efforts were made to minimize bias resulting from this but the possibility exists that other investigators would obtain different results.

Limitations

1. Because the interview method was used, the sample size was limited to 32 subjects. While this number should be sufficient to provide an adequate overall picture of the students' concepts, it is not large enough that the list of data obtained can be considered exhaustive. However, given the nature of the data sought, an

exhaustive list of responses is unlikely regardless of sample size.

2. Reliability is an important factor in all research studies. As the interview method was used in this study, reliability was quite difficult to control. As will be outlined in chapter three, a number of steps were taken to obtain maximum reliability within the chosen method.

Chapter 2

Review of the Literature

Science Teachers' Conceptions of the Nature of Science

Rubba and Andersen (1978) describe the nature of scientific knowledge along seven dimensions as follows:

Amoral: Scientific knowledge does not include directions for use. Moral judgement is not inherent in the knowledge but must come from those who wish to apply it.

Creative: Scientific knowledge is created by the human intellect.

Developmental: Scientific knowledge changes over time. Though it may be falsified or modified it may never be proven and must always be viewed in its historical context.

Parsimonious: Although complexity is not shunned, simplicity is always sought.

Testable: Scientific knowledge is subject to public empirical test. Validity of results may be supported by such tests.

Unified: Although science is often seen as consisting of discrete parts with names such as "Biology" or "Physics", it is understood that these are all merely facets of one larger systemized whole.

From these dimensions Rubba and Andersen developed the Nature of Scientific Knowledge Scale (NSKS), a likert scale instrument. The instrument was designed to see how students' views of scientific knowledge compare with the above. Results from studies involving the use of the instrument to date appear to indicate that few students' beliefs are in strict agreement with the model. As the instrument is an objective one, however, it does not point out what those alternative views are or to what extent or extreme the students tend to adhere to them.

Several of the studies reported in the literature showed concern over the adequacy of teachers' conceptions of the nature of science. Most of this concern was grounded in the assumption that the way a teacher performs his or her duties depends on his or her view of science. Teachers who view science as a collection of facts would therefore tend to teach the subject as a collection of facts. Teachers who, on the other hand, view science as a process would tend to take a more enquiry oriented approach to instruction. In many cases it is simply assumed that the teachers' conceptions of the nature of science will have a profound effect on those of their students. Evidence examined, however does not appear to support this idea.

In an intricately designed study, Lederman & Zeidler (1987) attempted to find out whether there really is a relationship between teachers' understanding of the nature of science and changes in students' conceptions of the nature of science. The Nature of Scientific Knowledge scale was administered to a sample of 18 teachers and the students in one of each of their classes at the beginning and end of a school term. During the intervening time, trained observers visited the classes to record the interactions in the classroom. After observations were complete, 44 classroom variables were identified. Based on the results of NSKS and on the observations, an attempt was made to see how the variables discriminated between teachers with differing conceptions of the nature of scientific knowledge. None of the variables except "Down Time" was found to discriminate significantly among the high and low groups. Lederman interpreted this as providing evidence that teacher behavior does not vary greatly as a result of conceptions of the nature of science. The result of this study appears to be that for teachers to simply have valid conceptions of the nature of science is not enough to influence students. These conceptions must be balanced with effective instructional strategies in order to promote valid concepts in students. Several other studies reported by Lederman & Druger (1985) and Lederman (1986a,b) indicate similar results.

<u>Students' Conceptions of The Nature of Science--Quantitative Studies</u>

It appears unlikely that students' conceptions of the nature of science are considerably in agreement with the major philosophical positions of the day. On the contrary, studies reported by Carey and Stauss (1968, 1970) provide evidence that students' views differ significantly from more accepted ones. More recent studies reported by Andersen (1986) and by Lederman (1986b) indicate that, although the differences may not be as great as once thought, students' conceptions still differ significantly from the accepted models. Unfortunately, these studies do not provide information indicating in what way the students' positions differed from the accepted models.

Evidence exists that students' conceptions can be influenced by the courses they take. Klopfer and Cooley (1963), using a large random sample, discovered that those students who had been exposed to the "history of science" cases performed significantly better on the Test On Understanding Science (TOUS) than did untreated students. However, two studies which appeared shortly after produced conflicting evidence in this regard. Trent (1965) attempted to find out whether students taking PSSC physics understood the nature of science better than did students enrolled in more traditional courses. The investigation controlled for mental ability and prior knowledge of science. The two groups consisted of students in the two types of courses in 52 schools randomly selected from schools teaching each of the two types of science curricula. TOUS and the Otis Quick Scoring Mental Ability Test were administered. Analysis of variance between the school mean scores on TOUS for the two types of curricula showed no significant differences, thus indicating that the PSSC curriculum was equally effective in attaining student science understanding as measured by TOUS. Trent pointed out that some differences did occur between different schools utilizing similar curricula, possibly indicating the presence of other factors, such as teacher attitude and teaching style.

Evidence somewhat in conflict with Trent's study was offered by Crumb (1965). The results indicated that students studying PSSC physics did in fact obtain better scores on TOUS than did students studying a traditional physics course although the fact that the sample was not random raises some doubt about the overall validity of the results. However Crumb did state that "their distribution by school size, type and location is believed to be quite representative of those in the area" (Crumb, 1965, p249).

As these two reports differ in findings while remaining basically similar in design, it is difficult to say for certain what a more general trend would be. Both studies were fairly regional. Each sample, though quite large, was only selected from one particular area in the United States.

It is possible that findings would tend to vary from region to region according to other variables external to the treatments. Both researchers express the belief that courses can make a difference in students' conceptions. Several other studies support this. Barufaldi, Bethel & Lamb (1977), Billeh & Hassan (1975) and Ogunniyi (1983) all found significant course effects on teachers' and prospective teachers' conceptions of the nature of science. Although those studies were concerned with the conceptions held by pre-service teachers and other university students, it is not altogether unreasonable to assume that similar effects would be found for high school students. No further published studies appear to be available in this area, however.

In society in general there may be an unwritten assumption that older persons are more philosophical than younger ones. It also appears to be assumed by many writers that older persons possess better conceptions than do their younger counterparts. Mackay (1971) investigated the way that students' conceptions about the nature of science change over time. In Mackay's study, TOUS was administered to a random sample of 1556 science students in grades seven to ten. The test was re-administered to 1203 of those students at the end of the school year. Comparisons of the mean scores indicated that students did improve over the school year, as the re-test score means were significantly higher. Furthermore, evidence was provided that students conceptions improved significantly with age as the mean sores of students in upper grades were significantly higher than those of the less advanced students.

Students' Conceptions of the Nature of Science--Qualitative Studies

An investigation undertaken by Rowell and Cawthron (1982) attempted to shed more light on the question of students' conceptions. A questionnaire was administered to 300 students and staff of several Australian Universities. From the results of this questionnaire it was concluded that most science-oriented students tested tended to agree with the more deductive Popperian model than with the socially oriented Kuhnian model. This study was unfortunately flawed in several respects. Its findings must be therefore interpreted with caution. No validity or reliability data were reported for the instrument used. In fac' there was no indication given that an attempt had been made to obtain this information at all. As the whole study was based on this instrument, the validity of the study is also questionable. In addition the sample was non-random, cor sisting mainly of volunteers. Hence it may not be representative and the results may not be generalizable.

A qualitative study was reported by Saunders (1986) in which information was obtained on the nature of science from students, professors and teachers. Subjects were asked to respond to the question **"What is science?"** The results were grouped and categorized. It was noted that teachers and professors tended to describe science as both process and product whereas the students tended to provide only limited answers such as "science is the study of ..." It was noted that 7% of the teachers and professors described science as knowledge alone whereas 2% of the students described science as consisting of both process and knowledge. Saunders' study is not without flaws. Essay tests are not very reliable and are often difficult to interpret. Saunders' model was also a very limited one, consisting of only two parts: knowledge and process. The study is nonetheless important as it shows that students' conceptions of the nature of science are general in nature and that they may, with time, become more precise. Finally the study provides some data about what teachers and students actually think about science rather than checking for a match against a constructed model of the nature of science.

A case study of a teenager's view of the nature of science, reported by George (1987), revealed much qualitative data. In particular, the subject interviewed appeared to see science as truth, thus indicating a view which tended towards the realist view described earlier. Some evidence was also given which indicated that the subject's views were somewhat similar to several of the scientistic views described by Nadeau and Desautels (1984). As this was a case study, the results are not generalizable although the study was useful in that the rich qualitative data indicated several areas for future study.

Recent studies by Aikenhead (1987), Fleming (1987), Ryan (1987) and Aikenhead, Fleming and Ryan (1987) also provide qualitative data on students' conceptions. These studies, which were but part of a much larger one, involved administering the Views on Science Technology Society Scale (VOSTS), an instrument developed by the authors, to a stratified sample of 10800 graduating high school students. In the study, students were asked to take one of several positions on each of several aspects of scientific knowledge, scientists, and science and society, and were also required to write a paragraph explaining their reasoning. The study showed a great diversity of students' views and provided indication that a broad range of explanations existed for those views.

Unfortunately there was some evidence that the position that the students took with respect to their views of the nature of science was not the one in which they actually believed (Aikenhead, 1987, p476). Students often expressed one view and in justifying it actually provided contradictory statements or statements which indicated belief in another view. A certain amount of immediate feedback from a researcher may have alerted the student to this fact. The limitations posed by forcing the students to adopt one particular expression over another may have also prevented them from fully expressing whatever conceptions or misconceptions they held. This may have been due to the fact that students were required to provide brief written explanations. Hence the results of the study may have been affected by the students' ability to put their thoughts on paper in the time allotted. Aikenhead, Fleming and Ryan (1987, p155) recommended further studies to provide greater clarification on, as well as the source of, students' beliefs and the firmness with which they held those beliefs. Semi-structured interviews were recommended to facilitate this. In addition, the authors indicated their beliefs of the directions in which future studies should take:

> The precision of communication (the goodness of fit) between a students' paragraph and VOSTS "student position" is much greater than the precision of communication between a students' paragraph and his or her "agree" or "disagree" response. If one objectively scored the VOSTS responses, one would sacrifice precision on the altar of quantitative methodology. (p156)

Fleming (1988), in a follow-up study, surveyed the views held by 200 chemistry majors in all four years of an undergraduate program at a Canadian University. Responses to the VOSTS statements in written paragraph form indicated that the views held by those students differed only slightly from those held by high school students. The use of semi-structured interviews in this study also provided a good deal of insight into the views held by those same students. Many of the students were found to equate science with the creation and verification of facts although a significant number indicated their belief that, in science, facts do not exist. Like the student interviewed by George (1987), in many cases, subjects were found to associate mission-oriented science with medical research. In addition, the results indicated that the students did not tend to take a critical stand, but instead accepted scientific knowledge as faith.

Other than the above studies, little more than sketchy data exist on the nature of students' conceptions. By and large, students' conceptions do not appear to be as well developed as those of their teachers. Given that most student's cognitive abilities are in various stages of development, it is unreasonable to expect them to have sophisticated notions of the nature of science as such conceptions would require a high degree of abstraction. Overall the amount of information available on the students' views of the nature of scientific knowledge is small. Given the great concern expressed about the importance of an understanding of the nature of the scientific enterprise, this is indeed surprising.

Research Methodologies

Two general methods have been used to study misconceptions related to a number of scientific concepts. These methods will now be reviewed for their general usefulness for the present study. Anderson & Karrquist (1983), Ben Zui (1986), Doran (1972) and Gardner (1986) have all utilized techniques based on the use of questionnaires and have succeeded in determining the prevalence of some common misconceptions. Such techniques, however, require that some knowledge be known beforehand about the nature of the misconceptions in order to be successful. A major advantage of questionnaires is that a large sample size becomes feasible. In situations where the general nature of the misconceptions is relatively unknown, studies based on interviewing techniques have proved successful. Hackling & Garnett (1985), Arnaudin & Mintzes (1985), Osborne and Gilbert (1980) as well as Watts (1983) are among those researchers who have successfully utilized such methods.

Interviewing procedures.

A number of data recording techniques are available. Simpson and Arnold (1982), for example, utilized note taking as the principal recording technique. This method results in reasonably brief and detailed accounts of the interview but also has several disadvantages. It is particularly susceptible to bias on behalf of the interviewer. Note taking cannot successfully show subtle differences imposed by the respondent's intonation. In addition there always remains the possibility that what is recorded is inaccurate or incomplete.

Several investigators, including Hackling & Garnett (1985) and Watts (1983), taped their interviews. The use of audio tapes offers significant improvements over note taking. Intonation is also recorded, thus leaving the investigator free at a later time to take such factors as confidence in one's answer into account. The taped interview may also be checked again by the same investigator or by another to check reliability or to check for errors of omission or commission on behalf of the investigator. The use of videotape has also been found helpful in several studies including those by Aguirre & Erickson (1984) and Erickson (1983). Video offers the additional advantage of allowing the investigator to see the subjects working. This technique would prove especially beneficial if the interview were centered around some particular tasks.

Researchers have differing opinions about the level of structure that should be imposed on the interview situation. As Posner and Gertzog (1982) note, the purpose of the exercise is to gain information from the students, not the reverse. For this reason some researchers such as Erickson (1983) leave the interview unstructured. Other researchers like Arnaudin and Mintzes (1985) as well as Sneider and

Pulos (1983), in the interest of conserving reliability, adopt a more structured style. All researchers attempt to maintain flexibility. The structure is used mainly as a guide. When situations warrant, the researcher is permitted to seek clarification.

A number of particular interviewing techniques also exist. Champagne, Klopfer, Desena and Squires (1981) describe ConSAT, a method for discovering the ways in which students structure various concepts. Basically the method involves the researcher presenting a number of concept names to subjects. The names are typed on cards and the student is told to arrange them in some logical order and to explain the reasoning used. The researcher has a sheet which contains all the concept names and connects them together with lines in the same way the student did. The reasons the student provides are written on the lines. The method has been used successfully by those authors in showing how the structure of concepts in geology change with instruction.

A technique labeled the Interview About Instances (IAI) has been described and used by several different researchers including Osborne and Gilbert (1980) and Watts (1983). The technique involves basically two phases. First the subject is presented with a series of cards which either do or do not illustrate a concept. Next the interviewer, by asking a series of probing questions, attempts to determine the depth of the subject's understanding of that concept. Osborne and

Cosgrove (1983) modified the IAI in an Interviewing About Events technique which involves the subject being presented with a series of events, such as water melting. The subject is then asked, through a series of probing questions, to explain the event in as much detail as possible. The authors have used the technique to show that subjects can have varying conceptions of change of state.

Analysis of data.

As recorded interview data is difficult to interpret directly, most researchers reduce their interviews to written transcripts. Most tend to favour verbatim transcripts, although a number of other techniques are available. Pines, Novak, Posner & VanKirk (1978) advocate paraphrasing the questions and responses into a series of declarative statements by the subject. This procedure has, however, been criticized as being flawed in that it may tend to "put words in the student's mouth", especially when the interviewer asks very specific questions which require only simple yes/no responses.

Although easier to interpret than raw interview recordings, transcripts are still exceedingly difficult to interpret as they contain so much unstructured information. To further reduce the data, Erickson (1983), Arnaudin (1985) and others have utilized conceptual inventories. This technique requires the researcher to examine the transcripts and attempt to extract all concepts and/or misconceptions expressed during the interview. In this way, a fairly lengthy transcript can be reduced to a set of fairly well-defined concepts or misconceptions.

Summary of Major Research into Students' Conceptions of the Nature of Science

Students' conceptions of the nature of science are unlikely to be in strict agreement with those of the major philosophers (Carey & Stauss, 1968, 1970; Anderson, 1986; Lederman, 1986b). A wide diversity of viewpoints and conceptions do exist. However those conceptions held by students are likely to be somewhat vague and undeveloped (Aikenhead, 1987; Fleming, 1987; Ryan, 1987; Aikenhead, Fleming and Ryan, 1987). Research indicates that those conceptions can be modified by appropriate instruction (Barufaldi, Bethel & Lamb, 1977; Billeh, 1975; Ogunniyi, 1983). Additionally it appears that students' conceptions of the nature of science tend to become more sound and reasonable as students mature (Mackay, 1971). It is unclear exactly how firmly those conceptions are held although research on other scientific concepts indicates that students are likely to hold tenaciously to existing concepts (Driver, 1978).

One of the early barriers to fruitful research on students' conceptions of the nature of science was the lack of agreement among philosophers on what was the nature of science. As much early research was based upon models which had been constructed by the researchers, the findings of many studies must be interpreted with caution as they may only apply specifically to elements of the models used rather than to the practice science as a whole. However, as Duschl (1985) and Hodson (1985, 1988) note, much of the earlier disagreement has been dealt with and more mutually agreeable models exist even though some difference still remain as was pointed out in Chapter one.

Although qualitative data have been made available by studies conducted by several researchers including Aikenhead, Fleming and Ryan, a number of questions on the nature of students' conceptions remain. These authors recommend the use of semi-structured interviews in future studies in order to obtain more detailed information on the nature of students' conceptions. The present study attempts to do this by examining in detail the beliefs of a sample of students in their senior year of high school. The following chapter describes in detail the procedures used.

Chapter 3
Research Design

Consideration of available data-collection procedures suggested two potentially profitable approaches. These were either to develop and administer an appropriate questionnaire or to develop and administer an appropriate interview schedule. Use of a questionnaire had the major advantage that it could substantially reduce the cost of the study by making it unnecessary for the researcher to be present. However it also had the disadvantage that answers thus obtained also depend to a great extent on the students' ability to express themselves in written form. As many high school students are seriously deficient in this area, results obtained in written form may not accurately mirror students' actual conceptions. In addition, essay items would not allow the researcher the flexibility required in probing subjects' thoughts in order to seek clarification. Overall it was felt that use of a questionnaire would increase reliability but decrease validity. Hence an interview procedure was used.

In addition, to facilitate the later analysis of the data, all interviews were tape recorded. Detailed note-taking such as that done by Simpson and Arnold (1982), was not utilized for several reasons. These included susceptibility to bias on behalf of the interviewer, inability to successfully show subtle differences which may arise from the respondent's intonation and the possibility that what was recorded might be inaccurate or incomplete. Due to the time-consuming nature of interview studies, sample size was strictly limited. Thirty-two subjects were involved. All interviews were audio taped. Videotape was not utilized as the bulk of the interviews centered around theoretical ideas and the investigator could see no additional benefits arising from actually seeing what the participants might do while thinking.

Procedure--Data Gathering

The interview guide.

Researchers have differing opinions on the level of structure that should be imposed on the interview situation. As Posner and Gertzog (1982) note, the purpose of the exercise is to gain information from the students, not the reverse. For the purpose of this study, a semi-structured interview was deemed to be the most appropriate approach. Due to the inherent broadness of the topic, too much structure would have resulted in a too narrow range of ideas. However for the same reason, too little structure would have resulted in too much data. The first stage of the study therefore involved the preparation of an interview schedule. As a completely structured interview was not desired, questions were of a general nature and were designed to elicit as much student response as possible. Additional prompts such as **"tell me more about..."** or **"what do you mean when you say..."** or even simply **"Why?"** were used as necessary. A certain amount of overlap was allowed between the questions to allow for possible triangulation as a means to allow the researcher to check for reliability. Overall, the guide was viewed as somewhat flexible in nature. Where situations warranted, room was left for clarification.

A two stage approach was used in piloting the guide. The initial draft of the guide was tested on five randomly selected students from an all-grade school. Notes were taken during the interview and the recordings were later checked to identify specific problems. In particular an effort was made to ensure that as few unnecessary cues as possible were provided by the questions. The guide was revised in light of the findings and was again piloted on three students randomly chosen from another all-grade school. As subsequent analysis of the recordings resulted in no further revision in the guide, it was judged satisfactory and ready for use.

The final form of the guide consisted of questions grouped in four major clusters. The guide is represented in Appendix A. The first cluster contained a set of seven questions of a general nature and was designed to obtain the subjects' conceptions of the scientific enterprise in general. In particular, the questions in this section were designed to establish student views of the domain of science, student views of scientific method and student views of change in science. The second cluster contained questions on the nature of scientific facts. Subjects were asked **"What is a fact in science?"** and were then asked to provide an example. The remaining questions in that cluster attempted to ascertain the relation between that fact and the scientific enterprise in general as well as to find whether subjects considered scientific information to be questionable and tentative or absolute. The nature of scientific theories was investigated by the third cluster. Subjects were asked **"What is a theory?"** and were then required to provide an example of one. The remainder of the questions were designed to elicit subjects' responses on the relationship between theories and science. In an effort to determine whether students' views were fundamentally instrumentalist or realist, a pair of questions were asked. Subjects were first asked what theories are used for and then whether they are models or realistic descriptions. In the fourth cluster subjects were first asked **"What is meant by a scientific law?"** Those who successfully provided a response were then asked for an example. Subsequent questions obtained clarification of subjects' concepts of the use and nature of scientific laws. An effort was made in this section to differentiate laws from theories and facts.

In places where specific examples were required, provision was made for backup examples. These were chosen with the intention that they would be simple enough to provide some measure of assurance that they were correctly understood. These backup examples were only used after the subjects stated their inability to provide their own or after a fairly lengthy period had elapsed after the question had been posed. No specific alternate questions were prepared. Individual subjects' problems with the questions were handled as they arose during the interview.

The sample.

Thirty-two students from nine schools in eastern and central Newfoundland participated in the main study. Six were from two large high schools in a predominantly urban district. Fifteen were from two large high schools in medium sized communities. Seven were from three small all-grade schools in small, rural communities. The remaining four students were from a small high school in a small, rural community. All were randomly selected from the senior class in each school. The ages of the students ranged from 17 to 20 years with the mean age being 17.6 years. In order to ensure that the sample was representative, sample selection was designed to provide a variety of scientific and academic backgrounds. In particular, the list of potential candidates was reduced so that it would result in eight subjects in each of the following groups.

Group A Academic Science: Students who had taken at least two level three academic science courses[1] chosen from Chemistry, Physics, Biology or Earth Science and at least two other academic science courses. Students also had to have achieved an academic average of 75% or higher in all high school subjects.

Group B Non-Academic Science: Students who had not achieved an overall 75% academic average but had otherwise met the requirements for group 1 by being enrolled in or completing two level three science courses as well as two other academic science courses.

Group C Academic Non-Science: Students who had taken less than two level three academic or other science courses but who had maintained an overall average of more than 75% in all courses taken.

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[1]Level three courses are the most advanced courses in the curriculum and are taken only by students in their last or last but one year in school. Typically each of these courses is spread over one academic year.

Group D Non-Academic Non-Science: Students who had not met the requirements for the other three groups. This group was composed of those students whose overall academic average was less than 75% and who had not completed two level three academic science courses as well as two other academic science courses.

These groupings were only designed to ensure a representative sample. They were not used as a basis for comparison. Each of the subjects was interviewed individually. These interviews took place both during and after school hours and required fifteen to twenty-five minutes each to complete. All subjects were informed that the interview would be audio-taped. At the beginning of each session, some time was allotted for the subjects to speak freely with the interviewer. This part, which was not recorded, was included in order to ensure that good rapport had been established. Following the formal interview, the tape was again stopped and the subject was again encouraged to speak freely about the interview. The names of each subject were recorded for future reference. However, each was informed that the interview data would be treated anonymously and that their names would not be mentioned specifically in the report.

Assumptions.

The interviewer was forced to make several assumptions about the subjects. First of all, it was assumed that they were responding honestly and not in some random fashion. The unrecorded portion of the interview was included specifically to enhance this. Before each interview, some time was spent explaining the purpose of the study, as well as emphasizing the necessity of honest answers. Secondly, it was assumed that the answers the students provided were consistent with their thought processes. By repeating several questions, this problem was minimized, as inconsistencies could be identified later when the transcripts were read. A third assumption that was made was that students did stay within one conceptual framework. Gilbert and Watts (1983) note that in interviews, students will tend to remain within one framework, but that when overheard talking among friends they may shift rapidly among several other frameworks as other subjects' thoughts influence theirs. Care was taken in this study, therefore, to minimize the chance that the interviewer did not influence subjects' thoughts to a significant degree. Finally it was assumed that the investigator interpreted the subjects' responses correctly. To provide some control of this, the investigator attempted to seek clarification when students provided ambiguous responses.

Data Analysis

As recorded interview data was difficult to interpret directly, the interviews were converted to written transcripts. Verbatim transcripts were utilized despite the difficulties in reading them caused by the numerous "Ah's", "Umm's" and rapid shifts of focus. Samples chosen from each of the four groups of subjects described earlier are included in Appendix B. Interviewer questions appear in bold type. The numbers which appear before the questions refer to the numbering system used in the guide. Although easier to interpret than raw interview recordings, the transcripts were still exceedingly difficult to interpret as they contained so much unstructured information. To further reduce the data, a conceptual inventory was constructed for each student. This required the researcher to examine the transcripts and attempt to extract all concepts or misconceptions expressed during the interview. In this way fairly lengthy transcripts were reduced to a set of more clearly stated and organized statements. The conceptual inventories are included in Appendix C.

An attempt to categorize findings in order to discern patterns was also conducted. The responses to each individual question were examined in order to identify any threads of similarity which may exist among subjects. In addition by checking the verbal explanations and rationales provided by the subject for each interview question, an attempt was made to ascertain the depth and breadth of understanding held by each type of student on each particular facet of the nature of scientific knowledge.

Reliability and validity.

The interview procedure, due to its dynamic nature, makes reliability extremely difficult to control and measure. Responses obtained in the interview setting depend to a great extent on the level of interaction between the investigator and the subject. However, several techniques exist which place some measure of control over the overall reliability of the interview. In order to minimize responses which might be cued by the interviewer, all participants were asked beforehand to answer as honestly as possible and were told that most of the questions had no "right" or "wrong" answers. In addition an attempt was made to periodically make counter-suggestions. The use of leading questions was, of course, avoided as these would almost guarantee that the interviewer's bias would affect the results.

A measure of reliability was also obtained by asking similar questions at different times during the interview. A number of questions were posed several times. For instance students were asked **"What is a theory?"** at one point during each interview. Later they were asked, after providing an example of a theory, **"How do you know this is a theory?"** Consistent answers at this point would thus indicate a degree of reliability. By appropriately structuring the interview, some assurance was also given that all subjects were treated similarly. However, as students may react differently to an interviewer, it is difficult, if not impossible, to ensure complete consistency for all interviews. The use of structured interviews offered some advantage over unstructured ones in this respect in that the validity of the interview structure could at least be confirmed by external individuals. Triangulation through the use of several related questions also helped increase the validity of the research.

Once the conceptual inventories had been completed, a check was devised for reliability. Individualized questionnaires were constructed by taking the inventories and altering some of the concepts to make them express the opposite of the ideas expressed by the subject. This was done for each of the thirty-two inventories. The resulting questionnaires were returned to the schools and the students completed them by indicating whether they agreed or disagreed with the ideas. It was thought that proceeding in this manner would require the students to be much more critical than they would have been had they been simply presented with the original inventories and asked to verify them. When the questionnaires were returned, they were checked against an answer key which showed the correct match to the appropriate conceptual inventory. The results were converted to a fraction of agreement. Once the procedure was completed for all the interviews, a coefficient was obtained by dividing the total of all correct matches by the total number of concepts checked. The resulting coefficient of 0.84 indicated that students were likely to express the same concepts 84 times out of 100. Samples of these questionnaires are included in Appendix D.

In order to determine an indication of rater reliability, the following procedure was also used: Each transcript was read by two or more separate raters. The raters, science teachers enrolled in a graduate studies program, then examined the related conceptual inventory and identified all statements which they did not view as justified by statements within the transcripts. Overall the reliability as measured by this procedure was quite high. Once again a quotient was obtained by dividing the number of undisputed statements by the number of statements examined. The quotient thus obtained was 0.94, indicating that, out of every 100 conceptual statements derived by this investigator from the transcripts, 94 would likely be derived by another investigator from the same transcripts. The checked conceptual inventories were additionally checked to see if any patterns could be detected in the way they were marked; patterns which would indicate systematic errors in the derivation of certain statements. No such patterns were detected. However, on the advice of the raters, a few changes were made in the wording of several statements.

One hundred and thirty separate, but sometimes related, concepts were identified. In order to facilitate examination of the conceptual inventories, the results were pooled and tallied using a spreadsheet which calculated the total number of expressions for each concept. The concepts were then separated into several related groups and tabulated. The tables thus formed consisted of lists of categorized representative statements followed by the number of subjects found expressing them. There were 32 subjects in the study. The totals within any one table do not equal 32 however as subjects made varying numbers of statements within each category. Most subjects' responses could be summarized with one statement however several subjects' comments had to be reduced to two or more statements while a few subjects were unable to provide decipherable replies within several categories.

At this point, to focus attention once more on the actual thoughts expressed, the transcripts were re-read. It was noted that most information was of a general nature. Some of the subjects were unsuccessful in providing decipherable answers to some of the questions in the guide while a few actually provided multiple answers. Some of the participants had great difficulty in supporting their views. In spite of this, a great amount of information was obtained. This information is presented and discussed in the next chapter.

Chapter 4

Results

Examination of both the transcripts and the conceptual inventories shows a considerable diversity in the student viewpoints. Several subjects spoke at length about the various areas of science while others were only able to provide brief, general responses. The subjects were able to converse satisfactorily on most of the questions in the schedule. However, as shall be mentioned later, some questions resulted in rather surprising answers. Generally speaking, the answers provided did not indicate well-defined or mature views of science. Most responses were rather short; subjects were not quick to elaborate on positions taken. Often subjects would respond to questions in a questioning tone perhaps indicating their lack of confidence in the answer. Collectively, the answers did seem to indicate that some type of conceptual framework was in place. Subjects rarely provided self-contradictory responses. The general vagueness of the responses did indicate that the framework was not well defined or non-rigid in nature. Finally subjects tended to be consistent in their use of vocabulary and concepts.

Overall, perhaps due to the generality of the responses, a wide range of ideas and views were noted during the interviews. The conceptual inventories were found to have 130 different, but sometimes related, entries. The low frequencies typically found to be associated with each concept also stand as testament to the general broadness found. The results, clustered in four main groups, will be expanded on below. Not every question in the interview guide will be examined in detail. Several of the questions were only included to determine whether subjects were providing consistent responses. The results shall be grouped according to the research questions presented in chapter 1.

Student Views of science

General views.

A brief examination of Table 1 shows that most subjects provided vague answers to the question **"What is science?"** Few were very long and many were accompanied by considerable periods of silence. A number of subjects provided multiple responses although frequent "Ah's" and "Umm's" in the transcripts provided evidence of the subjects' difficulty in providing satisfactory responses. Several of the students interviewed admitted to having given little previous thought to the nature of science. When pressed for a response, many

Table 1

Representations of Student General Views of Science[2]

Science involves explanation.	19
Science involves studying phenomena.	10
Science involves experimentation and the obtaining of new information.	4
Science involves the memorization of facts.	2
Science involves obtaining information on a variety of subjects	1
Science involves learning and applying concepts.	1
Science is a way of thinking.	1
Science is man's curiosity and desire to learn.	1

2 The numbers which appear in any of the following tables refer to the number of subjects who expressed the particular concept. As many subjects expressed multiple concepts, the table total need not be 32

were only able to provide answers such as "science is sort of figuring out stuff. There's no real set explanation for it I don't think. Sort of experimenting with different technology." Other answers were even less developed: "science is a lot of memorization and facts that you gotta remember." In fact few of the students tested showed evidence of having considered the question before at all. In many cases, subjects were incapable of providing little more than a few words as in the following response an academic-science student provided. "(laughs) Ah... it's chemicals and experiments--that's the way I see it."

As may be seen from Table 1, most of the answers could be clustered in two main groups, those who concentrated on "explanation" and those who concentrated on "studying". "Explanation" formed part of the answer for 19 of the subjects asked. Many responded that science involved obtaining explanations for why certain things happened, for example: "[Science is] The study of how and why things work the way they do," or "I would say it is the study of [pause] facts. More like not less more realistic... trying to find out a more realistic explanation of something rather than a philosophy. More facts, more realism." Some subjects' use of "explanation" included only natural, physical phenomena while others included only living creatures. As most responses which involved use of the word "explanation" were not investigated further, it is not clear whether the respondents regarded those boundaries as important. Ten subjects indicated that science involves "studying". Four subjects expressed the view that science involves studying life or studying the Earth while the remainder hardly elaborated at all. Exactly what was meant by "studying" was not made clear, possibly indicating that the subjects themselves were unclear as to what was involved.

Process oriented answers were much less common; a few responses dwelled somewhat on some of the processes of science, although none actually listed the traditional scientific processes. For instance one student stated that science was the process of obtaining information on a variety of subjects. Several subjects provided terms such as "observation" and "experimentation." As they were not inclined to go into detail on these and remained rather vague on their use, some doubt was left as to how deeply the terms were actually understood. As before, most were rather general as demonstrated by one subject's response to the question **"What does science involve doing?"** "I think it involves learning some set facts and theorems if you want to call them that and then applying them to other things." Overall, four subjects indicated that science involves experimentation and the obtaining of new information, one subject said science involves obtaining information on a variety of subjects and one said that science involves learning and applying concepts.

Two subjects took a different approach to the question **"What is science?"** and provided rather unique responses: "science is the curiosity of humans to study things they don't know about," and "it's ah a whole different way of thinking. You've got to think a whole different way in order to do science." Such answers were rather uncommon. It is interesting to note that only two subjects let their answers be confined within the normal disciplinary boundaries of science. Answers such as the following were quite rare: "science is many different fields of study. There's the study of motion, the study of physics, the study of chemistry, the study of biology and the functioning of the human body, the circulatory system. Biology is geology--not biology but science is--it covers many different fields and facets of study."

In order to try and further illuminate the question, subjects were also asked **"What does it [science] involve doing?"** Although most subjects were able to provide a response without any great difficulty, those provided were vague and typically of the form "sit in a lab all day long and do labs and study about different people and how different things came about," or "research, study and experiments." Attempts to obtain further elaboration of these responses were unsuccessful, suggesting a general lack of understanding in this area.

As general responses were noted in the pilot study, the question **"How is science different from other areas of study?"** was added to the guide. In responding to this question, subjects typically indicated that science was a more rigorous area than others. Answers such as the following were common: "It's more ... I'd say it's more complex and it's more ... other things. Let me think ... more to it ... like the study of it is different--there's more to be found out for one thing than other subjects like literature." In addition, subjects indicated that science, more than other areas, involved finding new information and explanations. Excerpts such as the following were also typical: "science is more of a study of what happens than like anything else. ... [pause] ... Science deals with like real life things like." In their responses five subjects provided more personal responses by indicating that science differed from other areas in terms of its value: "science to me is relevant to life. I'd rather sit around and talk biology and physics and chemistry and those subjects than talk about religion ... I don't care about religion or language or something like that. It's something that interests me." Overall, however, answers were more of the first type, indicating that the major distinction was one of complexity.

Motivation for research.

Each subject was asked **"What influences scientists to undertake whatever projects they are currently working on?"** Table 2 summarizes the response to this question. Only five subjects were unable to provide a satisfactory response. Clearly, curiosity and/or personal interest were the most often cited motivations behind scientific research. Twenty-five participants in the study believe that scientists perform scientific research to satisfy their own curiosity. Most of the responses resembled the following: "well they're kind of curious--everybody's curious and they like to find out what's behind it all so they do--they want to find out what's behind it all so they do experiments and stuff like that on it." In fact, many participants cited these as the only motivating factors behind research and when asked for further examples were unable to provide any. It may be inferred from this that most students view science as being performed by autonomous and self-directed individuals. These factors also indicate the general framework within which most students appear to be operating. As was mentioned earlier, the words "studying" and "explanation" formed part of most responses to the question "What is science?" Given this type of response, curiosity and interest would be therefore appropriate motivating factors.

Table 2

Representations of Student Views on the Motivation Behind Scientific Research

Scientists are motivated by curiosity and/or personal interest.	25
Scientists are motivated by society's needs.	9
Scientists are motivated by financial gain.	2
Scientists perform science to obtain new information.	2
Scientists are motivated by challenging tasks.	1
Scientists are motivated by ambition.	1
Scientists are motivated by possible practical applications of knowledge.	1
Scientists are motivated by external reasons.	1
Scientists perform science as part of their assigned duties.	1

Nine subjects also noted that need is often a motivating factor behind research. Examples from medicine were mentioned with the need for cures for particular diseases being the most frequent. A variety of other motivating factors including financial gain, ambition, the lure of challenging tasks and the basic desire to obtain new information were also mentioned. Each factor was only cited by one or two subjects in responses such as the following: "Well one thing is their educational background. Say if I like you work under a scientist it's a tradition the way a scientist works it's like you do it the way the older people did it and it might be changed. It is like a tradition like they got Gal- the way Galileo did experiments is basically the same as the way they does experiments today but a few changes," and "I think a lot of times they're so competitive with one another they each want to come up with solutions or something so they'll work and work until they do; they're very ambitious people," or "it could be something that's already like an idea or a theory that's around and he doesn't believe in it and wants to disprove it." Perhaps most significant was the relative scarcity of responses indicating that scientists perform science for financial gain or as part of their assigned duties. As much science today is performed by teams of individuals in private industry, one would expect that teaching in schools would reflect this reality. This is apparently not the case as subjects were not capable of providing much more than somewhat indirect references such as the following (note that "R" is the respondent and "I" is the interviewer in this excerpt and others which follow):

> (R) Well to me a scientist undertakes something like he finds something that he doesn't know about and he just gets an urge to find out why it happened.
>
> **(I) Is there anything besides interest and curiosity?**
>
> (R) Um [pause] he gets paid to do it! [laughs]

This finding, along with the overwhelming belief that scientists perform science out of curiosity or interest, suggests that students believe that science is a somewhat personal, as opposed to a cooperative, venture in that the practitioners are seen to be autonomous individuals. This belief may possibly be due to the way that science is presented in texts. Most case studies in the relevant curricula focus on the role of a particular scientist rather than on the general problem or research program. For example, the physics text used by many of the subjects focuses on the achievements of several exemplary scientists such as Galileo or Faraday. Use of such examples, which is common in text materials, therefore tends to cause focus on the work of individuals rather than on the evolution of ideas. In this way, students may therefore form the view that science is created piecemeal from the work of its greatest practitioners.

Scientific observation.

Each subject was asked **"What is the role of observation in science?"** Most subjects provided somewhat generic answers which could easily be extrapolated to many other fields of study. The results are shown in Table 3. The answer given by 22 participants was that scientists observe to obtain data. Responses such as the following were typical:

> **(I) What is the role of observation in science?**
>
> (R) Everything. Because if you don't observe you don't have any reason why to do anything. You have to have something to watch or to listen to or whatever in order to make a conclusion.
>
> **(I) So how, exactly, do scientists use observation?**
>
> (R) To base whatever they find out on so that if they say something they can back it up.

Only two other reasons were found in the transcripts. Two subjects stated that scientists observe at all times, sometimes to gather data and sometimes not. One student stated that while scientists often observe to gather data,

Table 3

Representations of Student Views on Scientific Observation

GENERAL STATEMENTS ON OBSERVATION	
Scientists observe deliberately to obtain data.	22
Scientists observe at all times.	2
Open-minded observation can yield unexpected but useful results.	1
STATEMENTS ON THE RELATIONSHIP BETWEEN THEORY AND OBSERVATION	
Observation is theory driven	8
Theories arise from observation	10

they also should keep an open mind as sometimes non-expected results can be significant.

An effort was made to determine the subjects' conceptions of the relationship between theory and observation. Through comments such as the following, eight subjects expressed a belief that theory precedes observation; that whenever scientists observe, they do so deliberately to either confirm or falsify a theory:

> Well observation is basically science because Ah... you observe--well you could watch experiments or populations or anything and you got to observe them and see if there's a difference--a marked effect by putting a certain cause in so if you can't observe it's all speculation. You gotta observe to Ah... prove your theories.

Most of those eight subjects appeared to view observation as being somewhat neutral in nature. None of them indicated that observation exists within a theoretical framework; that people's observations may be guided by their own theoretical framework. Generally speaking, therefore, it seems that the objectivity of observation was either assumed or not considered.

On the other hand ten subjects provided responses such as:

> Well you--well I think you have to like--like to really figure out something you'd have to observe it anyway to observe its behavior like to Ah... to do studies in labs you'd have to be there yourself to watch it and to make a conclusion of what actually happened.
>
> or
>
> It's important because if you're in a lab or something like that and you're doing some--I dunno--you're doing some sort of experiment or whatever and like you notice something that don't usually happen or if something happens that--out of the ordinary whatever--it's like if you're there--you observe it or whatever notice it could be something important to science or whatever 'cause it's always changing anyway like it might be something that someone's been looking for for years.

showing a belief that the relationship proceeds in the opposite direction; that theories emerge from observation. Such a view implies one of two additional conceptions. The first would be that scientific knowledge is constructed, that from observations scientists form the most plausible explanation; the one with the best fit. An alternative view to this would be that the scientific "truth" has its own real existence; that its presence can be determined by different individuals from the same data. Student responses were such, however, that it was impossible to determine which of the two positions was held.

Some responses were difficult to interpret. Most allusions to the relationship between theory and observation were somewhat vague. For 14 responses, the direction was either not expressed or unclear. In fact, several subjects appeared not to know much about scientific observation at all and, when asked, simply responded in a manner such as: "you're looking at the different way things react by seeing the way the different things react and respond." Such answers, while providing a more or less accurate description of observation, indicated a general lack of understanding of why or when scientists observe. Overall, seven subjects were unable to provide a decipherable response to the question. Only a few subjects indicated that observation is something which occurs all the time. That such a response was difficult to obtain is clear from the following discourse:

(I) Tell me what is the role of observation in science?

(R) That's like you observes your results.

(I) So why would you--why would a scientist observe?

(R) Why

(I) Yes.

(R) To see what happens when he mixed--or whatever.

(I) Ok so outside of experiments--this would be why he observed during an experiment--if the scientist wasn't doing an experiment, would he be observing?

(R) Yeah.

(I) Why [pause] why would he be observing?

(R) 'Cause he'd still be seeing everything, feeling everything and tasting.

(I) What [pause] what good might that lead to?... How might that help the scientist do some science?

(R) I dunno he might by looking around he might find a cure for a disease or something.

It appears as if the role of observation in science was not well understood by the subjects although indication was provided that subjects believe science does rely heavily on observation as the source of data. The subjects in the sample did not readily provide examples of how observation can be influenced by prejudice nor did the subjects refer to expected results or reasoned results. Instead they treated observation as the objective gathering of information from an experiment or the objective viewing of phenomena in order to explain it later. In addition, there was little or no evidence in the transcripts to indicate that subjects viewed observation in both ways. Only one subject expressed the view that scientists observe deliberately to obtain data and in general to obtain inspiration. Overall, while most subjects are aware of the existence of, and, importance of, observation, its exact role in relation to science appears to be quite unclear.

Scientific method.

Table 4 shows that nine separate responses were noted to the question **"What is a scientific method?"** They ranged from the very general responses such as "A scientific method involves experiments," or "[A scientific method involves] research" to rather detailed and singular responses such as the following.

> Um... set a plan like what you are going to set out to do like what your objective is and ah... what you might need to get to that final conclusion or whatever and um... gather information and put it all together and ...

Or

> Analyzation, observation, writing skills. Have to be able to [pause] You have to be able to generalize what you're going to analyze to study

Table 4

Representations of Student Views on what Constitutes a Scientific Method

A scientific method involves experiments.	7
A scientific method involves research.	4
A scientific method is a stepwise solution to a problem.	2
A scientific method involves hypothesizing, testing of theories through experiment and further modification of ideas if necessary.	2
A scientific method involves study, research and the application of scientific laws and formulas.	1
A scientific method involves formulas, labs and personal involvement with the subjects to be studied.	1
A scientific method involves planning, setting objectives and the analysis of information.	1
A scientific method involves analysis, observation and communication.	1
A scientific method involves the application of concepts and theorems.	1

> and you have to observe it carefully and record your observations, write them on paper or in thesis form.

Few of the respondents began their answer as "The scientific method ..." Most began "A scientific method ...," possibly indicating that they may believe there exists more than one scientific method. However as the question was phrased to include "...a scientific method", the respondents may have been merely copying the interviewer. Only two of the participants provided what may be termed the traditional response by stating that the scientific method involves hypothesizing, testing of hypotheses through experiment and further modification of the hypothesis if necessary.

Seven of the subjects indicated that a scientific method was one which used experiments. Four of the subjects centered their answers around "investigation" or "research" with three of those subjects indicating that a scientific method involved a planned investigation, and one indicating that it involved research in general. Two more subjects stated that a scientific method is a stepwise solution to a problem. Five singular responses were noted: a scientific method involves formulas, labs and personal involvement with the material being studied; a scientific method involves planning, setting objectives and the analysis of information; a scientific method involves analyzation, observation and communication; a scientific method involves study, research and the application of formulas and finally a scientific method involves the application of concepts and theorems.

Approximately one quarter of those interviewed only provided quite vague responses such as "... A procedure to perform a certain experiment probably. If you're talking in like in as a scientist probably just a procedure to perform your experiment." Typically these answers contained general reference to the words "investigate" and "experiment" although no indication was given as to exactly what was meant by those words. Several subjects associated a scientific method with the procedure used in the lab. When asked, they offered responses such as the following:

> The only one I know would be like in our--in our own science courses, when you're at a lab the method we have to carry out like an example of one of the labs we did or something?

Quite a number of subjects had difficulty with this question. The interviewer had to clarify this question frequently by restating it several different ways. In fact, 12 subjects were unable to provide a useful response at all as can be seen from the following extract:

(I) What is a scientific method?

(R) A certain way of doing something. A certain procedure.

(I) Like, for instance, what? Give me an example.

(R) God! [very long pause] I don't know [long pause] calculations about how to find [long pause] I don't know [laughs]!

or

(I) Can you tell me what is a scientific method?

(R) No! [laughs]

(I) We often talk about a scientific method in textbooks and so on, whatever that happens to be. It makes me wonder just what that method is.

(R)... [pause] ...

(I) In other words, what I'm wondering is if you want to categorize what scientists do as a set of things, how would you state what they were?

(R) Discover new things about the environment. ... [pause] ... Try and explain the ecosystem.

The results were disappointing in that so many of the subjects were unable to provide a useful response. The previous two excerpts demonstrate how meaningless the term is for those subjects. It appears that for twelve subjects in the study, three eighths of the sample, the term "scientific method" is meaningless and for most of the remainder, the term has only a slightly more developed meaning. This phenomenon may possibly be due to teachers and curriculum developers who have become quite wary of the notion of "The Scientific Method" in light of modern, more socially oriented views of science. Although much criticism is warranted against use of the term "**The** Scientific Method", one should perhaps not assume the non-existence of "**A** Scientific Method". Many problem solving methods, such as trial and error, may be classified as unscientific. Others, including many expressed in Table 3, are decidedly scientific in nature. Perhaps the overall problem is due to the lack of a clear-cut distinction between scientific and non-scientific methods.

Change in science

Most subjects appear to have a view of science which is basically cumulative. When asked **"How does science change?"** they provided a variety of answers such as "Science changes because they find out more new things every day and it's never static, it's ever changing," and "Well, people change and the environment changes so this causes science to change because the more things change the more scientists begin to develop and know what's going on," or "Well it changes with us as we develop." Such responses showed an affinity for the view that science is progressing steadily towards the truth. In fact, if one examines Table 5, it can be seen that eight subjects expressed the view that science is continually improving. Through statements like "With different advancements like with microcomputers it makes it easier," or "I guess it changes every year because of advanced technology and more scientists in the world today ... greater levels of education," those subjects expressed the view that the focus of change was on either the data gathering techniques or on technology in general.

Fourteen other subjects expressed the cumulative view in a different way. Seven of the subjects believe that the focus of change is on the information itself. Through statements such as "Well, through the years I guess, way back, not much was discovered and as time progressed, more things were discovered and found out. Now it's pretty well ... a lot of stuff has been figured out. It's more challenging today I think," or "As more and more knowledges come about because of more experiments or observations from other scientists. They can base something they want to base on another person that done the experiment," those subjects showed affinity for the belief that science changes as new information is added and illuminates old. An additional three subjects indicated that science changes as information becomes more specific, three more believe that science changes by becoming more complex while only one believes that science changes by becoming broader.

Table 5

Representations of Student Views on Change in Science

Science is continually improving.	8
Science changes as new information is added and illuminates old.	7
Science changes generally as society changes.	5
Science changes as theories or concepts become more complex.	3
Science changes as the information sought becomes more specific.	3
Science changes by becoming generally broader.	1
Science changes as naive ideas are replaced by more rigorous ones.	1
Science changes as previously accepted information is discredited.	1
Scientific change may be revolutionary.	1

Five subjects focused on society as the root of scientific change. Three of those were rather vague such as "Well it changes with us as we develop ... as we think we develop more and science kind of adapts to it because with AIDS for example ten years ago scientists didn't have to worry about it but now they do so we change with it to try and find a cure or a treatment or whatever ... change along as we do." One of those subjects indicated that man's perceptions of science may change. Finally, one of those subjects, by stating "More or less today scientists think that anything's possible like before, say fifty years ago if it's unexplained like it's an act of God or something and like now they can explain it now or they won't say anything foolish as that," indicated that science changes as naive ideas are replaced by more rigorous ones.

Falsificationist views were scarce. In fact only one subject stated that "Science changes with more ... more recent discoveries. Might one discovered might discredit another one, right? ... change it all around," and thus indicated that science changes as previously accepted ideas are discredited. No other subjects showed any tendency at all towards this view. Truly Kunhian views were equally scarce. Only one student suggested that scientific change can be revolutionary. Overall, six respondents were unable to provide a reply to the question while seven actually provided more than one reply.

It appears that many students confuse increased technology with scientific change. A number of subjects were asked **"If you were to contrast the science of the 1990's with the science of the 1940's, what would be the difference?"** Most responded in a manner consistent with the following: "Well they got better equipment and stuff like that to Ah... go into more detail to find [pause] to experiment." For these subjects, the word science is likely to be strongly linked with the use of recently developed measurement and recording instruments rather than with the other processes of science.

Subjects did not readily indicate whether this change process would end or not or whether or not absolute truth was in fact obtainable. Actually many of the respondents seemed somewhat unaware of what change in science actually was. Perhaps this was related to the generality of the responses to the previous question **"What is science?"** and, although understandable when viewed in this light, is still quite indicative of subjects' difficulty in establishing the domain of science.

Student Views of Scientific Facts

Subjects were asked first of all **"What is meant by a fact in science?"** Most of the subjects concentrated their responses on the concept of fact by indicating that generally it was something that was proven. Some typical responses were: "Something that is proven without a doubt to be true," and "A fact is something that is scientifically proven,". or "A fact? A statement that's true and that always will be I guess." In many statements it was clearly evident that subjects were not distinguishing scientific facts from facts in general but were using the word "scientific" as a qualifier synonymous to "superb" or "excellent" thus indicating that a scientific fact was one worth more than just an "ordinary" fact. This is perhaps once again related to the generally vague definitions of science typically provided by the subjects.

Subjects were then asked to provide an example of a scientific fact. Quite a few subjects had difficulty in isolating a particular fact. Those who could often provided rather intriguing responses such as "Water is made up of two hydrogen atoms and one oxygen atom," or "Charles Darwin's theory of evolution. It's a proven fact." That these were not facts at all appeared to be not noticed by the respondents. Despite these initial difficulties, the respondents were able to provide some well-defined views on facts and information in science. This is illustrated in the discussion below.

<u>How scientific facts are obtained.</u>

Subjects were asked **"How are scientific facts obtained?"** Table 6 summarizes the responses. Twenty-one

Table 6

Representations of Student Views on How Scientific Facts are Obtained

Scientific facts are obtained through research and experiment.	21
Scientific facts are obtained through observation.	2
Scientific facts are obtained by experimentally testing hypotheses.	1
Scientific facts accumulate as people react to perceived problems.	1

subjects expressed the view that research and experiment forms the basis for scientific facts. Most subjects provided only brief answers similar to the following: "Research, research and experiments," or "Through what a person saw or heard in the experiment that they based their conclusion on." Once again it can be seen that subjects made much use of the terms "research" and "experiment". If one compares the answers provided to this question to those obtained previously for the question **"What does it [science] involve doing?"** and notes the similarity of responses, it may be concluded that many subjects believe that the obtaining of facts constitutes a large part of the activity of science. Little indication was given of the process by which this knowledge gains acceptance. Most subjects appeared to feel that enough research would be sufficient to establish information as scientific fact. Subjects who attempted to elaborate on the process usually only noted that experiments and other investigative techniques need be replicable, as evidenced by the following excerpt:

> But experimenting a lot of experiments more than likely because you can't just do an experiment and something happen and say well 'this is a fact.' Every time this happens, this is what the end result is gonna be. You've gotta do it over and over again and see if there's some consistency there.

Two subjects indicated that scientific facts are obtained through observation, one stated that scientific facts are obtained by experimentally testing hypotheses, and one stated that scientific facts accumulate as people react to perceived problems. Most subjects expressed a belief that scientific knowledge is proven; the word "proof" was one which appeared quite often during the interviews. Whether subjects in general tended towards an inductive process or a deductive process was not clear from the transcripts although two of the subjects indicated that they tended towards an inductive process while one indicated that the process was more deductive in nature. Due to the lack of useful responses in this area, exactly what was meant by proof cannot be completely discerned. Seven of the subjects were unable to provide usable responses.

The nature of scientific facts.

To see whether subjects tended towards an absolutist or tentative view of scientific knowledge, they were asked **"Are scientific facts open to question?"** The findings, which are summarized in Table 7, indicate that the tentative nature of scientific knowledge is well understood. 27 subjects expressed a belief in the tentativeness of scientific knowledge although there were differences in the degree to which the tentativeness is held. For instance, several of the subjects were quite adamant in their belief and clearly

Table 7

Representations of Student General Views on The Nature of Scientific Facts

Scientific facts are tentative.	17
Scientific facts are tentative in some instances; they may be proven also.	5
Scientific facts are open to question but are in all likelihood correct.	5
Scientific facts are proven.	4
Scientific facts are agreed upon by the whole scientific community.	1

indicated the necessity of maintaining an open mind as, for example, in the following statement:

> Oh there's no doubt about it they're open to question. If one scientist comes up with it and another group thought that something else was wrong or something sure they can be proven wrong 'cause there's no precedence I don't think in science.

The most frequently provided reasons for the tentativeness of scientific facts were that either the methods for obtaining them were flawed or that viewpoints are apt to change with different societal demands. The dangers of staying within a particular mindset were expressed by several participants. Several indicated that questioning scientific knowledge was the key to progress; that if knowledge was not questioned it would stagnate. The possibility of unknown interventions was also addressed by several subjects in statements like "Well there's always the question 'Is this true?' It's quite possible that there could be some unexplainable force there that no one has quite put their fingers on."

Overall, as may be seen from Table 7, 17 of those 27 subjects had no reservations about the tentativeness of scientific facts. Not all subjects were as firmly convinced. Five of them indicated only that some scientific facts are tentative while some are actually proven beyond doubt. Five more indicated the belief that although scientific facts were open to question, the process of questioning them is likely to be futile. For example:

> Well if [pause] question it to one point but if something in science--I mean if seven or eight different scientists or ten or a hundred or whatever scientists did this experiments and they all came up with this way of--this certain way that everything showed up well I mean it would be considered fact--but you can always question it of course.

Finally, only one subject, by stating "Well I guess they have to find out for themselves and then they have to go before a committee of other scientists and they'll probably have controls on it and find out if it really is factual," indicated affinity for the consensus view. Only four subjects rejected the tentative view completely by stating that scientific facts are absolute and proven beyond doubt.

Subjects speaking about scientific knowledge tended to use an objectivist standpoint. In speaking about scientific facts, they often referred to them as "them", perhaps expressing the belief that all knowledge would have the same significance for all audiences; that all people would derive the same meaning from a particular piece of information, whether or not they agreed with it. Only one respondent actually noted during the interview that the way one views a piece of knowledge may change with time. For the most part, subjects expressed the belief that scientific knowledge was something that applied equally to all as in: "It's something that's real and concrete; Something that is the actual cause; it's proven and it's proven theory." It is interesting to note here also the use of the word "proof". As was mentioned earlier, most subjects responded to the question **"What is a scientific fact?"** by indicating that it was something that was proven. That these responses form a marked contrast with the subjects' stated belief in the tentativeness of scientific facts is quite clear. One explanation for this would be that for many of the subjects in the study the word proof has a very casual meaning. Something which those subjects refer to as proven may be for them still tentative as their notion of proof only amounts to little more than evidence or examples.

Student Views of Scientific Theories

Student understanding of the nature of scientific theories was also investigated through a series of eight questions. Through these questions, an attempt was made to discern student conceptions of the general nature of theories and to determine whether subjects held an instrumentalist or a realist view.

General understanding of theories

Table 8 shows that definite agreement existed as to what was a theory. Twenty-four of the subjects, when asked **"What is meant by a theory?"** indicated their belief that a theory is a possible but not proven explanation. Some examples of their actual wording include "Somebody has an idea about something but it hasn't been proven," and "A theory is an idea that a person has about a certain certain ah... observation he has made," or "A theory is a proposed reason for something the way it works but it's not proven like there's not-probably--there's probably a way of proving it but it's just an educated guess made by someone." The fact that this was worded so many different ways indicates that the concept is likely to be well understood in a general way. If it was rotely memorized, most subjects would probably have responded in a uniform manner.

Four other respondents indicated a somewhat similar view. Through statements such as the following: "It's an idea somebody has that something should happen this way for some result. Like they're not sure but they thought that it might happen," and "What you think will happen in a certain situation I guess," indication was given that subjects' views of theories were geared more towards prediction or description of behavior rather than explanation of the reasons behind it.

Table 8

<u>Representations of Student Views on What Constitutes a Theory</u>

A theory is a possible but not proven explanation.	24
A theory is a proven fact.	1
A theory is a person's idea.	1

One subject stated that a theory was a proven fact. Another indicated that a theory was an idea but was unable to explain any further. The remaining six subjects were unable to provide a response.

The subjects were then asked **"Can you give me an example of a theory?"** Only three of the respondents actually stated a theory. Sixteen more simply named a theory, with evolution being by far the most common, without offering additional explanation. An additional four subjects provided non-rigorous examples such as "All trees are green," or "If I drop a rock it will fall." The remaining nine were unable to provide an example. Examples such as the kinetic molecular theory and the theory of evolution were suggested to those nine subjects in order to provide a basis for further discussion.

Subjects were then asked **"What makes this a theory?"** The response provided by 20 subjects was that theories differ from other statements in that they have not been proven. In fact, this was the only clearly stated difference offered by any of the respondents although two subjects, through statements such as "Because there were so many contradictions to ... to it and other scientists who have contradicted his theory also have proof of why they didn't believe him. But as Darwin did, he had someone who believed him too, right?" and "Because there's two or three different explanations for it and they're all theories because there's no one set idea," went on to suggest that it was the multitude of other possible explanations which caused statements to be classified as theories. One other subject offered the following: "It's a theory because we can't see it; we can't understand it; we can't grasp it; touch it--it's not real to us," perhaps indicating that theories are abstract concepts.

The nature of theories.

In order to determine whether subjects subscribed to a realist or an instrumentalist view, they were asked **"Would it be more accurate to say that theories are models or that they represent the world as it really is?"** The results are summarized in Table 9. Most subjects responded "models", thus indicating instrumentalist viewpoints; that theories existed to facilitate explanation or further work. When asked why, 14 subjects responded that theories were models because if they represented the world as it is, they would not be theory but, rather, fact. In effect, most subjects believe that theories are models because they are tentative.

Eleven of those 14 subjects added an instrumental dimension to the above definition. Through statements such as the following: "Because to describe the world like it really is, it would have to be like a true fact. But where it is not really ... not really proven or whatever it's just a model which we go by to try and understand ... try and understand what they're trying to talk about," and "They're

Table 9

Representations of Student Views on The Overall Nature of Theories

THEORIES AS MODELS OR AS REALISTIC DESCRIPTIONS	
Theories are models because they are tentative.	14
Theories are assumed to be exact descriptions of what is happening.	6
Theories are models.	4
Theories are models because they provide workable explanations in lieu of absolute truth.	3
Theories can be either realistic or models.	2
THE EXISTENCE OF ALTERNATIVE THEORIES	
More than one theory can compete to explain the same event.	19
Only one theory is widely accepted at any	2

not proven so you cannot really say that they really make up the world or they are what the world is made of. So we use 'em as models to help us understand stuff ... understand the world," indication was given that theories are also models out of convenience; that they exist to facilitate explanation. Three more of the respondents offered a slightly more mature instrumentalist reasoning, for example "Because, like, all theories are not true. So they're just models ... see what it's like ... we go by 'em until we find something that's more stable." In stating such viewpoints, subjects also indicated comprehension of the dynamic nature of science, that science is apt to change with time as situations dictate. Four subjects indicated that theories are models but were unable to provide further explanation. A strictly realistic view was expressed by six of those interviewed. Although they were unable to provide a logical explanation, they did indicate belief in the idea that theories actually represent the world as it is. Two subjects indicated that theories could be either realistic descriptions or models.

Subjects seemed to have no difficulty with the idea of multiple theories. This view, which is Lakatosian in nature was expressed by 19 of those interviewed when asked **"Is there such a thing as a strong as opposed to a weak theory or can there be only one theory which satisfactorily explains a given phenomenon?"** Those same subjects also showed understanding of how a weak theory could compare with a strong theory:

> Yeah there can be strong and weak theories like weak theories can be like theories that don't really have much backing 'em up like no real evidence just more or less what was someone's opinion without any hard core evidence backing 'em up whereas like a strong one you got a lot of evidence going for it and like there's a lot of proof and stuff like that to help ... help it make it truthful and more Ah... like more into what it was they were studying right?

and

> No, there can be a strong and a weak theory for the simple fact that a strong theory could be probably based on something that four chances out of eight it could be true but a weak theory could be two chances out of eight that it's true.

Views such as the above show that students have had experience with multiple theories at least on a rudimentary level. Whether or not they put this ability into practice has not been demonstrated. Only two subjects indicated that only one theory is widely accepted at any particular point. The remaining 11 subjects in the sample were unable to provide a useful response. It is interesting to note at this point the slightly absolutist language used by the subjects. Words such as "proof" and "true" in the two above excerpts provide some indication that subjects believe that the superior theory may actually be reality or at least a closer approximation of reality.

The function of theories.

As most subjects appeared to be expressing an instrumentalist orientation, it became important to discover why they considered theories important. All participants were therefore directly asked **"What is the function of theories?"** While this question initially confused some, most were able to provide satisfactory answers. Table 10 summarizes the results thus obtained. Eleven subjects responded that theories exist to either explain or communicate scientific concepts and ideas. In this way, theories could either communicate scientific concepts to the scientific community or to the public at large:

> Well it's like--well--it's like they could have pieces of the puzzle but they do not have the whole puzzle so it gives scientists or the public a way to sorta understand like a theory helps you state what you're researching.

An additional ten respondents, through statements such as "Well you base your experiment on a theory so a theory would be really like a topic of your experiment," and "It

Table 10

Representations of Student Views on The Function of Theories

Theories explain or communicate scientific concepts.	11
Theories function as building blocks upon which further research is based.	10
Theories facilitate the extraction of conclusions from experiment.	1
Theories stimulate thought.	1
Theories are used to question things.	1
Theories are used to improve the human condition.	1

gives you a basis on like how to question an experiment or how to go about doing it and I guess it gives you a purpose for going about doing it," also suggested that theories stimulate further research by either functioning as building blocks upon which new work can be built or by providing a solid base for criticism. Four singular responses were also noted: theories facilitate the extraction of conclusions from experiments; theories stimulate thought; theories are used to question things; and, theories are used to generally improve the way in which we live. The remaining seven subjects in the sample either provided vague answers such as "a theory could be used to help a scientist at his project," or were otherwise unable to provide a usable response.

How theories change.

Subjects were also asked **"Do theories ever change?"** The results are summarized in Table 11. Although almost all of the sample agreed that theories do change, there were a variety of views expressed on exactly what types of change occur. Five stated that theories could be disproven. Excerpts such as the one shown below demonstrate that a certain number of subjects do believe that science proceeds by the replacement of weak theories by more adequate ones.

> Yes Umm... for instance with the theory of evolution first there was Lamarck who said that when like adaptations that we have like someone could acquire during their lifetime would be

Table 11

Representations of Student Views on Change and Theories

Theories may be proven true.	12
Theories may change.	9
Theories can become law.	6
Theories may be disproven.	5
Theories may change as detail is added.	2
Theories do not change.	1

> passed on to their child but then people shunned that idea and like laughed at him when Darwin came up with his theory that it was the struggle of the fittest and the best species survived. So that shows that some theories are disproven.

Twelve subjects also demonstrated a certain inclination towards a naive realist orientation by stating that theories can be proven true, that theories can become law or both. The prevalence of such statements forms a marked contrast with the instrumentalist responses discussed earlier in the section on the nature of theories. It must be noted, however, that not one single student responded to the question **"How do theories change?"** by indicating that they can be proven true or become laws. That result was obtained from a later question dealing with scientific laws.

Nine of the subjects, in statements such as "More evidence, more facts that will change a theory or alter it. New technology again I guess," and "Sure I guess when you get new evidence and new facts. Yes," suggested that theories do change, but these subjects did not provide further details. Two subjects stated that theories change by becoming more detailed while only one subject indicated that theories do not change. Overall seven subjects were unable to provide a useful response.

Student Views of Scientific Laws

The modern views of scientific knowledge discussed in Chapter 1 place great emphasis on its tentative nature--a far cry from the earlier notion of science as being a search for the fundamental laws of nature. Nonetheless, the term "scientific law" hasn't disappeared from use. Given the rapid rate of development and increasing complexity in many areas of science, for example in those relating to the search for the fundamental structure of matter and energy, it appears most unwise to assume that any scientific knowledge can be regarded as absolute in nature.

The findings discussed earlier indicated that students clearly understood the importance of maintaining a tentative view towards science. However as many subjects also frequently used the word "proof" and appeared to have only a very general view of the term "scientific fact", some question was left as to how deeply understood was their conception of the tentative nature of science. A law viewed in the sense that it describes with complete accuracy or explains with complete confidence the behavior of an object under a specified condition is anything but tentative. Subjects expressing such a view would therefore have to be considered as having an absolutist view of science. On the other hand a view which treated laws as statements which operate as above but only with a high degree of confidence could be still viewed as tentative.

The final eight questions in the guide dealt with views on scientific laws. A wide variety of views as well as one major misconception were expressed. The results are discussed below in terms of subjects' general understanding of laws and of the function of laws.

General understanding of laws.

Subjects were asked **"What is meant by a scientific law?"** then **"Give me an example of a scientific law,"** and finally **"Why is this a scientific law?"** The results of these questions are summarized in Table 12. Overall, 15 respondents indicated that a law was a proven fact, theory or procedure. Seven of those 15 subjects expressed complete confidence in scientific laws. Statements such as "To me a scientific law is something which has been proven beyond the shadow of a doubt", "I'd ... I'd say a law ... a law is something that is true; that is proven. It's like a fact," and "A scientific law is it a law it's something that's really true it's like, it's like a statement that's true, you can't change it, it's just there and y'know," expressed views which contradict the tentative nature of scientific knowledge.

As was mentioned previously, 15 subjects used the word "proof" as part of their explanation of the term "scientific

Table 12

Representations of Student General Views of Scientific Laws

A law is a proven fact, theory or procedure.	15
A law is a known fact.	10
A law is a mandated research procedure.	8
A law is a statement of expected behavior.	3
A law is a practical statement formed from several theories.	1

law". Exactly how this proof was obtained was not always made clear although five of the subjects implied that they assumed the proof was of an inductive nature by using such explanations as:

> I would say being called a law, they must have seen the results and they must have tried the results different ways and came up with the same result each time. With a theory they probably only tried it once or twice and different people tried it and they came up with different results so each people have their different theory and way to have it ... the law is something which if different people have tried it and got the same results

> or

> Lots of experiments. Just keep trying and it keeps happening so [pause] there.

Six of those 15 respondents, through statements such as "Well it started out as a theory and out of that theory he proved that certain things are the way they were. It became a law out of that," and "It's a proven theory that ... that acts all the time within certain exceptions," indicated a belief that laws were theories which had matured and had withstood the test of time; in essence they echoed what Rubba, Horner & Smith (1981) have termed the "laws are mature theories" fable. For three of the subjects, laws predicted future events or behaviors with a high degree of accuracy and were thus statements of expected behavior:

> I guess a law could be what usually happens like you could expect it to happen. Like the law again unlike poles attract. It's almost written down, it's gonna happen, it's law. If it don't happen there's something wrong.

Several other subjects provided answers such as "I'd [pause] I'd say a law [pause] a law is something that is true; that is proven. It's like a fact," and "'Cause it's Umm ... occurs anyway [pause] should occur," that were more of a general nature thus indicating that despite the fact that they know that laws were trustworthy pieces of knowledge, they were somewhat unaware of the specific nature of laws.

The distinction between a law and a fact provided great difficulty for subjects. Their difficulty in doing so was quite clear in their explanations, for example:

> A law is something that rules it like [laughs] Ah... I think they're alike like a fact is [pause] I dunno [pause] A law is something that somebody said works and proved it but a fact is like it's there; it's like anyone can see it kind of thing.

Some respondents were unable to make any distinction at all and either responded that the difference between the two was that more confidence could be placed on a law than on a fact or said that the two were basically the same.

When asked **"What is the difference between a law and a theory?"**, fully 21 of the respondents used the word "proof" as the basis of distinction. Through statements such as "A theory is something that has not been proven but could be proven true or false. A law is something that has been proven," and "The difference between laws and theories is that laws are proven facts and theories are someone's ideas which can be improved on or changed," subjects once again expressed views which are absolutist in nature. Only five subjects, through statements such as "I would say that a theory is something which is not definitely proven but a law is generally accepted by everyone ... a theory by a few people ... not yet accepted ... it may not be," maintained a more tentative view. The remainder either did not make a distinction or provided answers which were unclear.

A significant number of the subjects provided a quite unexpected response to the question **"What is a scientific Law"**: "I don't know [pause] scientific law [pause] guess it's something like a fact. [laughs] it's a procedure to follow," or "Something you've got to follow in order to do research." The incidence of answers similar to the above was quite high. Eight of the subjects tested, fully one quarter of the sample, associated the term "scientific law" with a mandated research procedure. It appears as if a number of the subjects tested have not been formally introduced to the concept of a scientific law and are instead associating the term with the more commonly used legal context. Several of the subjects even used legal references in their explanations:

> Well, a law I would say, is an expected thing to do like driving 90 on the trans Canada highway that's expected right? and if you're over that excessively it's sort of unexpected. I mean in science you're expecting a certain thing to happen and you're almost guaranteed it's gonna happen so I guess they tells by the law. If it don't happen it's almost like breaking it.

As the subjects who responded in this manner were not found to be related by school, sex or class, it appears as though this may be a fairly widespread occurrence.

The function of laws.

The subjects had little difficulty providing answers to the question **"Why do we have laws in science?"** The results are summarized in Table 13. The most frequently provided response, one provided by 12 respondents was that laws exist to provide a common, stable, knowledge base. Seen in this light, laws may be seen to unify science as in, for example

Table 13

Representations of Student Views on the Function of Scientific Laws

Laws consolidate science by providing a stable knowledge base.	12
Laws set directions for future research.	9
Laws guide science by defining accepted procedures.	3
Laws are used to explain or communicate science.	3
Laws check the validity of experimental results.	2
Laws help prove new information.	1
Laws encourage cooperation among scientists.	1
Laws stimulate interest in research.	1

"It would be a backbone so that everyone would have a constant basis like finding things out they won't use their own way of finding [pause] there's one constant law for answering things." For still more subjects, this stable knowledge base is the expected end product for science and perhaps even the reason for science: "We have laws because we have a need for proven facts. If everything is theories then there is nothing that is certain. With laws we know that there are things that we don't need to improve; that we know are true. If everything was theories then there'd be no certainty."

Another response, an instrumentalist one which was provided by nine subjects, was that laws provide avenues for future research. For example:

> Maybe it gives you a [pause] like the law of use and disuse. Something to expand on, could use it as, say here this is what somebody thought but we can expand on it to bring it up to date or whatever like.

or

> So that we have something to base our facts and experiments on. You can use it to justify some kind of experiment or procedure or observation.

This conceptualization may imply a somewhat cumulative view of science with laws functioning as fairly well-defined steps on the path towards "truth." Three more subjects viewed laws as items of convenience; things which would streamline and guide the practice of science by defining accepted procedures: "to shorten processes or Ah... I mean if it is there and it's always the same why not make it into a law and use it instead of going through whatever you had to do to prove one thing to go on to prove something else." For these subjects laws may also be viewed as a desired product although not necessarily an end-product as future use of them would be assumed. According to three more subjects, laws play a communicative role. As they were well-defined, laws facilitated communication and, therefore, explanation:

> Well if you never had laws it would be harder to explain how certain things work right? Because a law ... basically you could put it down in a formula and bingo! you got it right?

For one of those subjects who did not make the distinction between the legal and scientific contexts, the purpose of laws was, as expected, to keep all scientists "on track" as may be seen from the following excerpt "To keep people like on track I guess. That's something like why we have laws like police laws and everything else." Two more subjects stated that laws are used to check the validity of experimental results. According to this view, only findings which could be explained by an existing law would be considered correct. Three other singular views were presented: laws help prove new information; laws encourage cooperation among scientists and laws stimulate interest in research.

Overall, the general understanding of laws cannot be considered mature. In particular, the frequent use of the word "proof" coupled with the general consensus that laws are the desired end-products of science indicates the real possibility that subjects' conceptions of the nature of scientific knowledge and in particular its tentative nature may not be fully understood. Additionally, the frequency with which the misconception identified earlier appeared provides further justification for concern over the nature of students understanding of laws, as many subjects were completely unaware of what laws were at all.

The Prevalence of Scientistic Views in the Sample

As a final check on the nature of subjects' views, the transcripts were examined once more to find evidence of scientistic viewpoints, as described in Chapter 1. Elements of scientism were easily located in all but six transcripts. In fact most subjects demonstrated more than one of the inaccurate views described earlier. The results are summarized in Table 14

Table 14

<u>**The Prevalence of Scientistic Views in the Sample**</u>

Naive Realism	13
Blissful Empiricism	6
Credulous Experimentation	13
Excessive Rationalism	17

Thirteen subjects, through such statements as "Science is just ... I find it just ... you can't argue with the way things ... there's not much room for argument," and "Well a law comes around out of a theory. Like you start off with a theory and then you conclude the theory with your law," indicated a belief that at least some scientific knowledge reflects reality. In addition, in statements such as "[science is] just the study of why things happen and the way things are and just finding out questions, finding out answers to questions," subjects further reinforced the naive realist view.

Other subjects manifested this view by stating how scientific facts change "... like if they were a bit incomplete like if they don't explain everything. Like the theory of an atom. They're not sure but they think it's happened," or by stating that theories "... can be corrected if they're wrong," thus suggesting that there is a correct theory. Still others based this view on the belief that we were expected to assume that theories were exact descriptions of reality in such statements as "I think this is an exact way of saying what's going on 'cause that's the way we assume things are like y'know."

By stating that scientists observe "... to find out how and why something happened or what caused it to happen, I guess," or "... to watch it as it happens and to try and get as much information out of watching it as it happens," six respondents demonstrated some elements of blissful empiricism. Another subject, when asked how evolution was discovered responded "Study and observation of the creatures of the Galapagos islands."

It was sometimes difficult to determine whether or not this scientistic viewpoint was held. Only instances in which subjects indicated that knowledge arose directly from observation were actually counted as blissful empiricism. Statements such as "observation is very important because that's what you base your conclusions on later which is what ... what we get out of it so it's very important to watch what you're doing and observe it very carefully," were not included as they did not indicate a direct link from observation to knowledge.

One student, when asked how scientific facts arose responded that "I think it was someone had an idea ... Newton ... Newton had an idea and he wanted to figure it out so he just tried it and made a prediction and tested it out." Another stated "Enough experiments just proved that it had to be." Still another said that scientific facts arose "... from experiments I guess," thus showing some indication of credulous experimentation, the belief that experimentation can result in the verification of hypotheses or theories. Overall, 13 subjects in the sample showed some degree of credulous experimentalism.

When asked how does science change, one student responded "As time progressed, more things were discovered and found out. Now it's pretty well ... a lot of stuff has been figured out." By statements such as "Theory I think is something that needs to be thought of more and researched more to get a fact," and that theories could be used "... to do further research to find out the actual truth behind it or whatever," a total of 17 respondents demonstrated some degree of excessive rationalism; the belief that science can someday lead us to truth. This overall belief in truth, as discussed earlier, provides additional evidence that most students' conceptions of science are essentially cumulative in nature.

Elements of blind idealism, the belief that scientists are completely unaffected by happenings outside their professional area, were not found directly in the transcripts and were not tabulated. However the overwhelming frequency of the belief that scientists perform science out of interest provides some amount of indirect evidence as to its existence.

In short, scientism does seem to be quite prevalent among members of this sample although not to an extreme degree. although the vast majority of the sample did give some indication that many of their views were scientistic in nature, none provided drastically scientistic views. That those views are present in so many subjects is, however, noteworthy.

In this chapter the findings of the study have been reported in detail. A summary, as well as the overall conclusions are presented in Chapter 5.

Chapter 5

Conclusions

Summary of Results

Subjects had great difficulty in describing the domain of science. The responses to the general questions on science were extremely vague. Overall it appears as though students view science as a means to explain natural and physical phenomena in a variety of areas. They tend mainly to equate science with research in general. Additionally, students view science as something done by individuals working out of interest; perhaps mainly in a university setting. The only other major purpose-directed scientific research area described in any detail by the subjects was in the area of medicine. Students do not appear to think readily of commercially-funded scientific research but instead concentrate on more personally directed research.

The relationship between theory and observation seems to be a neglected area in science teaching as few of the subjects interviewed expressed the view that the world we see is modified by our "theoretical lenses." Subjects expressed neutral views of scientific observation. Perhaps this is related to the general lack of understanding of the term observed in many of the interviews. Today's widely accepted view that observation is theory driven was not expressed to any great degree by the respondents. Most, by providing rather simplistic explanations about the role of observation, indicated a lack of well-developed views in this area at all. In addition, although subjects did not show preference for the hypothetico-deductive scientific method, the generality of responses received shows a lack of clear understanding about what constitutes a scientific method and how one could distinguish between scientific and non-scientific methods.

In general, subjects tend to view science as cumulative. Students by and large believe that science is progressing and that more and more information is being discovered. The process whereby this knowledge gains acceptance seems to be of little importance. Subjects appeared to assume that, once discovered, new information would gain instant recognition. That this is highly unlikely, owing to delays in communication coupled by peoples' faith in their existing beliefs, appeared not to be considered. Additionally, the subjects showed little or no understanding of revolutionary science in a Kuhnian sense. Although several did note that theories can fall from favour, the process was not viewed to be common.

The extent to which students believe in the tentativeness of scientific knowledge was unclear. Subjects had no difficulty whatsoever with the term "scientific fact". None of the respondents suggested that, in science, factual knowledge was to be considered provisional and tentative. Most asserted that scientific facts are "proven". However, most subjects also indicated that scientific facts are open to question. They also stated that theories were tentative but often went on to state that they could be proven as laws. Exactly what constitutes proof was not made clear but some doubt was left as the extent to which the subjects believe in the tentative nature of scientific knowledge.

Most subjects expressed the view that theories are possible but not proven explanations. However they gave no indication whether they view theory as an organized body of information. Most responses indicated that theories are seen only in relation to singular events. It appears that a rather casual use was being applied to the term. Theories were thus seen as limited in scope to explanations of specific phenomena. Subjects, when asked **"What is science?"** or **"What does science involve doing?"** made no use of the word "theory" in their answers and left the overall impression that science only involved finding explanations or answers to very specific problems. Subjects seemed unaware of the use of theory in the broader sense encompassing a whole plethora of supporting concepts, terms and explanations. Most of the subjects' views had a decidedly instrumentalist orientation as they appeared to measure the worth of a theory against its ability to explain. Only a few subjects actually expressed the view that theories often do attempt to provide accurate descriptions or explanations of the world as it is. Those who indicated this had great difficulty expressing their explanation.

Many subjects had difficulty in discussing the nature of scientific laws. In fact several subjects showed no understanding of the term whatsoever. Most of the sample associated proof with law. A number of subjects, when asked, had great difficulty in distinguishing scientific facts from scientific laws. There was no overall consensus on the use of scientific laws, perhaps due to the general lack of understanding which existed in this area, although approximately one third of the sample indicated that scientific laws were the desired end-products of science.

Perhaps the most interesting result was one which, unfortunately, cannot be illustrated from the transcripts. In each case, after the interview was completed, the tape was turned off and the investigator and respondent spent some time conversing about the interview. In almost every case, subjects expressed surprise as to the nature of the interview. Many admitted to having given little previous thought to much of the material in the interview--a fact evidenced by many of the comments in the interviews. Some of the respondents commented that the material in the study was, for them, quite difficult and new. Overall it appeared that science education had been, for the respondents, nothing more than the establishment of a variety of scientific concepts and facts. It also seemed as though little attention had been given to the overall organization of scientific knowledge or to the nature of science. Although most of the subjects had been exposed to a wide body of theory and had been, in most cases, provided with a fairly solid understanding of scientific concepts, they had not been taught **about** science. They had not been introduced to such concepts as scientific revolution or the realist-instrumentalist dichotomy. That this was the case was indeed unfortunate, especially as most respondents expressed a desire to learn more about this area of science.

Implications for Teaching

Programs with a better philosophical basis.

The philosophical underpinnings of science education programs must be dealt with in a deliberate, systematic way. By paying insufficient attention to this element of education, many existing programs have been based on tacit and perhaps inaccurate or outdated views. The use of such programs has led to the fostering of the many inaccurate scientistic views discussed earlier; views completely misaligned with current philosophical thought. Attempts to present more philosophically based views of science must compete with the many views students already have. These views have probably developed from a variety of sources including, for instance, television and casual conversation with peers, teachers and parents. That these views are many and varied was observed in the present study and has been documented by others including Aikenhead (1987), Fleming (1987), Ryan (1987) and Aikenhead Fleming and Ryan (1987). Likewise the belief that they are likely to be held very tenaciously receives support from a variety of sources such as Driver and Erickson (1983). For this reason, appropriate teaching strategies must respect those views and enable students to see the shortcomings of those deemed to be inadequate. Failure to so will likely result in students either rejecting the instruction or simply accepting it non-meaningfully.

An overall curriculum plan suggested by Hodson (1988) may be quite effective in presenting a more philosophically valid view of science. The program would spend considerable time presenting pre-paradigmatic science. During this time, students would gain knowledge of the vocabulary of science, become adept at several related skills and would establish the general domain of science. In this way students would gain possession of the various tools necessary to understand the nature of science. This part would constitute the greatest part of the students' science education. Once students gained sufficient mastery of basic scientific concepts, they would learn the structure of the information as well as the processes through which it is organized and gains acceptance. Students would also be introduced to the mechanisms which govern both normal and revolutionary science. This part of students' science education would take place in the senior years at which time it could be reasonably assumed they had developed the appropriate cognitive skills and strategies to learn the material in a meaningful way.

As students appear to view science as something which is mainly sparked by curiosity, it would also be useful to include within science programs descriptions of what actual scientists do on a day-to-day basis. Through case studies and personal comments by actual scientists, students might come to view science more as a product of humanity as a whole. In particular, cases should focus on research programs rather than on the works of individuals so that students could develop a better understanding of how science operates in relation to the rest of society.

It has been shown (Champagne and Klopfer, 1981) that the use of a particular course does not necessarily imply the use of the philosophical underpinnings behind it. In order to strengthen the match between intent and actual classroom practice, such programs must be accompanied by appropriate pre-service or in-service training. Failure to do this will doubtless lead to a maintenance of traditional, teacher directed, teacher delivered, content oriented programs.

<u>The use of language.</u>

The use of language in the classroom must be carefully monitored by the teacher. Words used in a precise sense by the teacher may well be interpreted in a much less precise--if not completely different--way by the student. In particular this study has illuminated problems with the words "fact", "theory" and "law". The blurring of these terms has been observed in the interview transcripts. Teachers need to place theory in its proper perspective and show students how scientific theory consists of quite complex and carefully studied concepts. Failure to do so may result in students having only a very general conception of the term.

The importance of currently accepted theory in science needs to be more clearly presented. In addition, the simplicity of the theory testing which takes place in the classroom should be emphasized. Students must be clearly shown that ordinary laboratory activities differ markedly from true scientific research. The results of this study have clearly illustrated the consequence of such casual views--the subjects only expressed limited views of the scope of theories. Theories were seen as suggestions or explanations of individual occurrences rather than systemized and tested schemes. As a result, most subjects presented very unclear views of the organization of scientific knowledge. If those subjects had been better educated about the proper role of theory, the results may have been quite different. Use of the term "scientific law" needs to be clarified similarly. Many subjects in the present sample showed a lack of understanding of the term. This is a cause for concern. Once again the problem is related to vocabulary usage. Students associate the term law with its more common legal connotation. It is possible that if the term was clarified and placed in its correct context, the problem might disappear.

Directions for Future Research

A number of questions remain unanswered. Many subjects used "proof" in their answers. Although some indication was provided of their use of the term, it has not been completely established exactly what students feel constitutes proof. Do students see proof as inductive? Do they view proof as deductive? Can it be both? When a fact has been "proved," is it irrefutable or can it be reinterpreted in light of new evidence? Is new evidence likely to appear in our lifetime? The answers to these questions could, in themselves, provide the basis for study.

The realist-instrumentalist dichotomy has not been completely illuminated. This study produced some conflicting evidence about subjects' overall conceptions. It remains to be seen whether this confusion can be lessened by appropriate instruction which places emphasis on the role of theory and which makes the distinction between theory and model. Clearly an experimental study in this respect would be of much use. Examples of four of the five inappropriate or scientistic views of science described by Nadeau and Desautels were located in most of the transcripts. However the design of the study did not allow for the determination of the extent to which these views were held. Further studies or research might provide educators with much additional information in this area.

Finally it should be noted that, although this study provided information on students' views of science, it does not claim to provide an all-encompassing report of students' views. The sample was limited to part of one province in Canada. Although there is no reason to assume that different results would be obtained elsewhere, the repetition of a similar study elsewhere would be potentially useful in broadening the scope of the findings of the present study.

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Appendix A

The Interview Guide

1. **The general nature of science.**

   a. What is science?

   b What does science involve doing?

   c. What makes science different from other things?

   d. How do scientists know what to do. That is what influences scientists to undertake whatever projects they are currently working on?

   e. What is a "scientific method?" Give an example.

   f. What is the role of observation in science?

   g. How does science change?

2. **The nature of scientific facts.**

   a. What is meant by a fact in science?

b. Give me an example of a scientific fact? (For magnets, unlike poles attract. $A_g = -9.8 m/s^2$. There are 4 N. Bases in DNA.)

c. What makes this fact scientific?

d. How do you think it was obtained?

e. Are scientific facts open to question? Why?

3. **The nature of scientific theories.**

a. What is meant by a theory?

b. Give me an example of a theory. (KMT, Darwin's theory of evolution, theories of formation of the moon, relativity, atomic theories)

c. How do you know this is a theory?

d. What is the purpose of theories? How are they used?

e. What is the difference between a theory and a fact?

f. Would it be more accurate to say that theories are models or that they describe the world as it is?

g. Do theories ever change? How?

h. Let's say we wish to explain a certain event. Is there such a thing as a strong as opposed to a weak theory or can there be only one theory at any given time? Give me an example.

4. **The nature of scientific laws.**

   a. What is meant by a scientific law?

   b. Give me an example of a law. (Newton's 3rd, gravitation, conservation laws)

   c. Why is this a law?

   d. How did it become a law?

   e. What is the difference between a law and a theory?

   f. Why do we have laws in science?

Appendix B

Samples of Interview Transcripts

Subject: Male
School: Large High School in Large Community
Group: (A)--Academic Science

The first question concerns the way science proceeds

(1a) What is science?

The study of how and why things work the way they do.

(1b) What does science involve doing?

I don't know.

As a scientist went about his business, what kind of things would he do?

Study why things happen I guess. Find out why ... pretty well the same as the first question.

To do that how would the person study?

Gather facts and hypotheses. Predict I guess the outcome of whatever or how whatever things ... or do tests.

(1c) Tell me how you think science is different from other things?

Um it's not like literature there's like not one set ... one set answer for any question or any things happen. Science is just ... I find it just ... you can't argue with the way things ... there's not much room for argument.

(1d) How do scientists know what to do? That is, what influences scientists to undertake whatever projects they are currently working on at any given point in time?

Um curiosity [laughs] to ah... improve methods of anything ... medicine or ... write something down or try and do it a different way.

(1e) What is a scientific method?

I guess a procedure; a way that you ... hmm ... method ...

Ok let me rephrase that - I guess it's a bit bad. If you were a scientist and you were about to undertake a project, what kinds of things do you think you would wind up doing?

Um... set a plan like what you are going to set out to do like what your objective is and ah... what you might need to get to that final conclusion or whatever and um... gather information and put it all together and ...

Then you've got it.

(1f) What is the role of observation in science?

Um... I'd say a big part of it. That's another hard one.

Why would a scientist observe?

Again to find out how and why something happened or what caused it to happen I guess.

(1g) How does science change?

New technology. better ways of ... more efficient ways of doing things. And Ah... I guess ... ... [pause] ...

Alright let's talk about scientific facts.

(2a) To you, what is meant by a fact in science?

Something that is proven without a doubt to be true.

(2b) Give me an example of a fact.

God gave us four legs! [laughs]

How about for a magnet unlike poles attract. Alright what makes that fact scientific?

I guess because of the scientific method again and the way you go about finding that the information is true ... that it is a fact ... that opposite poles are .. whatever you said!

(2d) How do you think it was obtained in the first place?

Experiments.

Do you think that it was discovered deliberately or by accident?

I'd say possibly by accident. It could have been discovered ... I don't know. Electromagnet was discovered before magnets ... was it?

No [laughs] at least I don't think so.

(2e) Are scientific facts open to question?

Yes.

Is it reasonable? Is it worthwhile?

To question. Ah... unless you got some pretty good evidence or whatever. Evidence ... you gotta back up your question. Or if there is some flaw in the fact or I guess or some variations ...

Let's go on to theories now.

(3a) What is meant by a theory?

What you believe might be the reason why something happens but you're not positive there's no given facts or based on facts.

(3b) Give me an example of a theory.

evolution

(3c) What makes it a theory?

It's not proven.

(3d) What is the purpose of theories?

To Ah... build on and gather evidence. To help build on or forward your theory I guess or promote your theory and Ah... I guess a lot of times before that it's been proven to work and you get a theory or whatever ... keep at it or whatever and you may make it or prove it a fact.

(3e) What is the difference between a theory and a fact?

A fact is proven or backed up by evidence or experience or whatever and a theory is based on facts and could or could not be true.

(3f) Would it be more accurate to say that theories are models or that they describe the world as it really is?

models

Why is that

Because if they say that they are describing the world as it really is that would be fact.

(3g) Do theories ever change?

Yes.

Ok, how?

More evidence, more facts that will change a theory or alter it. New technology again I guess.

(3h) Let's suppose you wished to explain a certain event. Is there such a thing as a strong theory as opposed to a weak theory or can there be only one theory at any given time?

There can be many theories. Could be a weak theory [laughs] Ah... a weak theory could be many theories why something happens but I guess a strong theory would be the one that most people believe ... could be based on the most facts. A weak theory would be that it could happen this way but probably not.

Ok scientific laws is the last thing.

(4a) What is meant by a scientific law?

A rule or ah... it's a fact or something to go by. Something that could be said to always be true.

(4b) Give me an example.

Scientific law ... this is shocking! I should know one ... physics ... $E = mc^2$

(4c) Why is it a law?

Because no matter what variables you use and how ever you use an equation like that example, that ratio will always be equal or common.

(4d) How did this become a law?

Proven through facts or experiment I guess. Many times used many times.

(4e) What is the difference between a law and a theory?

A theory is not proven and a law is. A law Ah... is backed up by facts and a theory again I guess isn't. It's just an idea or ...

(4f) Why do we have laws in science?

To shorten processes or Ah... I mean if it is there and it's always the same why not make it into a law and use it instead of going through whatever you had to do to prove one thing to go on to prove something else.

(Conclude Interview)

Subject: Female
School: Large High School in Medium Sized Community
Group: (B)--Non-Academic Science

So the first question is very general ...

(1a) What is science?

It's about ... I'd say it's about theories and laws of life and nature and how everything works and that's about it I guess.

(1b) So what does it involve doing?

Well like I said it's different laws and theories like it could be like the theory of creation, that man came from Adam and Eve or like the theory of evolution where man came from an ape where Darwin and Lamarck like had theories about Ah... how things--how people evolved like the struggle of the fittest and stuff. Basically that's all it involves it's like ...

So what kinds of things would you do while you were doing science.

I don't understand what you mean.

What kinds of activities are involved in doing science?

In class?

Or suppose you were a scientist.

Eexperiments I guess and finding out how things work and trying to prove y'know if this was really how it worked or have evidence to show.

(1c) What makes science different from other things?

It's--it's--it's not proven like some things are not proven it's like I said it's theories--theories are not proven facts. And it's not like--not like physics like in Ohm's law it's like it is a proven Ah... formula like and like you can't prove we evolved from Adam and Eve.

(1d) How do scientists know what to do? In other words what influences scientists to undertake whatever projects they are currently involved in?

Well I guess it's from like past experiments that's been taken like I really don't know how it started like ... like for instance using a control and stuff, right? But like basically I'd say they just learned it from like scientists in back, earlier years.

(1e) What is a scientific method?

Umm... a procedure to perform a certain experiment probably. If you're talking in like in as a scientist probably just a procedure to perform your experiment.

So could you give me an example of something that would be a scientific method?

Do you mean like in terms of just a lab or ...

yeah.

... [pause] ... well we did a lab in chemistry not too long ago and we had to use pipetting and stuff so we method was we had to learn to use the pipette and Umm... basically like measure dilute solutions and stuff and that was what the method told us to use the pipette and how many ml of what solution and stuff.

(1f) What is the role of observation in science?

Well it really tells what you learned or shows actually that the results of the experiment and you can like compare, more or less like your experiment to someone else's or even to past experiments done right? Just to see the difference that you observed?

(1g) How does science change?

I guess with Umm... Everything else is like evolution. Things have changed like from back years ago there was no paved roads or Umm... transportation wasn't as easy as it is now and stuff like so I guess it has evolved around learning and everything else.

If you were to compare the science of the 1940's with the science of the 1990's, what would be the differences?

Umm... What is known now compared to what was known then for instance like in chemistry like they're still learning new things today than what they knew in 1940. Umm... and basically the equipment that is being used and Ah... what actually has been proven or what theories actually have evolved.

I want you to talk about facts in science now.

(2a) Tell me what is meant by a fact in science?

It is proven it is like Umm...it is something which is not a theory but it's like you got *proof* to show that this is really what happened or this is really true. It's like basically that is it it's just something that you can show that is proven.

(2b) Can you give me an example of a scientific fact.

Humans reproduce. Umm... That's proven true 'cause if it wasn't we wouldn't be here now.

(2c) What makes this fact scientific?

Well it's a part of nature and Ah... human reproduction is a part of nature and Umm... nature is like all of us and everything around.

(2d) How do you think it was obtained? Or in general how are scientific facts obtained

I'd say basically through learning and proving experiments and stuff like we're proof that there's such a thing as human reproduction. If it wasn't a fact or if it wasn't proven then we wouldn't be here.

(2e) Are scientific facts open to question?

That would depend I guess on what topic you're talking about. Umm... You can't question human reproduction as I said earlier probably with Ah... something like outer space ... that's probably still a theory well actually it's not because space ships, shuttle have been sent up and that but like you question really is it like what it is or is it further than outer space anything else in the galaxy type of thing.

I'll get you to talk about theories now. First of all ...

(3a) What is meant by a theory?

Theory is basically an idea which is not really proven but has got evidence - got evidence which will support that theory.

(3b) Can you give me an example of a theory?

Umm... Theory of evolution, that man was evolved from apes like because of similar bone structures found in apes that can be compared to humans and often you can see in a book how the shape of a skull had changed to make a human skull and that's basically it.

(3c) How do you know that these things are theories? What sets them apart?

Well it's like you can't prove that we evolved from apes Umm... they just like that just evolved like I really can't tell you the only thing I can say is that it is not really proven but scientists have found little bits of evidence to support it.

(3d) What is the purpose of theories?

To help find like common - more or less common sense or way of thing nature works or basically to Ah... God! I can't word this-- just to find how like everything is coming out like everything the way it is now it must have been some way it came out.

(3e) What is the difference between a theory and a fact?

Like I said theory is something which is like an idea which is not really proven but it has some evidence to back it up but like a fact is like you've got proof of what you've done and there's something now that can prove something was really true back probably in--in the 1940's right?

(3f) Would it be more accurate to say that theories are models or that they describe the world like it really is?

I'd probably say that they're models because like you can't prove that a theory is like the life now the way it is you can't prove that we evolved from apes and you know what I'm saying and it's a back--like something to fall back and to give us a reason why we are like we are.

(3g) Do theories ever change?

Yes Umm... for instance with the theory of evolution first there was Lamarck who said that when like adaptations that we have like someone could acquire during their lifetime would be passed on to their child but then people shunned that idea and like laughed at him when Darwin came up with his theory that it was the struggle of the fittest and the best species survived. So that shows that some theories are disproven.

What kind of a procedure is involved say in changing a theory?

Umm... first I guess you would have to have a better theory that you think would back up a lot of things like I'm sure that when Darwin did his theory about evolution like showed that Lamarck's theory was wrong. Like when Lamarck studied giraffes he like studied long necked giraffes and short necked giraffes. He figured that when a giraffe stretched its neck that like he would like it would stretch and his Ah... and his children would have long necks too, But it wasn't true because there was like some short necked and some long necked but the long necks survived because of the leaves on tress were higher and he just showed that it was Umm... the theory of the strongest will survive was better so like he just like blew that theory out of the water.

Does this procedure of changing theories, is it a long drawn out procedure or is it quick? How ... what is it?

I guess it would be long because like you can't just go out and say "Well I'm gonna change this theory now!" You got to have time to perform your experiment to back it up and to get evidence to show that your theory is a little more realistic than someone else's.

(3h) Let's suppose you wished to explain a certain event. Is there such a thing as a strong theory as opposed to a weak theory or can there be only one theory?

Well I guess there's a lot of theories like in the world which like have not made the books of science like a girl in class this morning said well what if we're all aliens and we don't know it! So it's like a weak theory right as compared to like Darwin's theory which has been in many science books.

Right the last thing deals with scientific laws.

(4a) Tell me what is meant by a scientific law?

A law which--a law is something which like is fact more or less than is theory. It's something which would probably prove the laws of science like you often heard tell of like human reproduction and stuff so that's more or less law it's like its set and you can't change it.

(4b) Can you give me an example of a law.

It's like I said humans reproduction is like humans do reproduce some maybe are not able to have children but that is to do with the body and deformities like but basically humans do reproduce.

(4c) Why do we call them laws then?

Because I guess it's because we got evidence to show that this is really happening and that it is really hard to change it like you can't say some time in the future that humans won't reproduce or Ah... that fish are not gonna swim it's just basic law that can't be changed.

(4d) How do scientific laws become laws?

I guess through time people adapted to the idea of like normal things like Umm...the sky is blue and people do reproduce and that fish do swim and birds do fly it's just something that has evolved through time and they accepted it.

(4e) What is the difference between a law and a theory?

Well a law is like something that--it is much like scientific fact; something that you really can't change and well a theory is something which is an idea that you can change like if someone comes up with a better theory like I said with Lamarck and Darwin like.

(4f) So what is the purpose of laws in science?

Umm... Just to find the basics of how - not really of how things work but like Umm... the way things are it's like I said birds fly, fish do swim, that's it.

(Conclude Interview)

Subject: Female
School: Small High School in Small Community
Group: (C)--Academic Non-Science

I'm going to ask you four general questions and each one will have seven or eight separate parts to it. The first question concerns the way in which science proceeds.

(1a) What is science?

Oh! [laughs] I would say it's the study of how things work like, natural things, like anatomy and natural phenomena like light and things like that.

(1b) What does it involve doing?

I think it involves learning some set facts and theorems if you want to call them that and then applying them to other things and it's ah a whole different way of thinking. You've got to think a whole different way in order to do science.

(1c) What makes science different from other things?

Well you can't really go home, for example if you've got an exam the next day you can't really take it home and just memorize. You've got to know what you're reading. You've got to understand it before you know it especially in physics. Biology is a little bit different

(1d) How do scientists know what to do? In other words, what influences scientists to undertake whatever projects they are currently working on?

You mean if he's doing an experiment or something? Ah... I'd say probably interest or something that he thinks needs to be perfected or invented even ah... something he thinks maybe the world needs or it could be something that's already like an idea or a theory that's around and he doesn't believe in it and wants to disprove it

(1e) What is a scientific method?

[laughs] Let's see ... [pause] ... a scientific method would be ah... using this kind of thinking I was talking about before I guess instead of just memorizing and drawing from your knowledge you kinda think about it. Look at it from different points of view.

(1f) What is the role of observation in science?

It is probably one of the biggest things you gotta do. It's important because if you're doing an experiment or something you gotta look at it and observe what's happening I think if you don't you're ... what's the point!

When does a scientist observe?

What do you mean?

Before an experiment? After? or during?

Oh throughout.

(1g) How does science change from year to year?

It changes with the times. For example, ah... you'd assume that someone that's investigating gravity now would use different ah... things than Galileo used so he used different techniques and different materials and things like that and as they go along they find out more so they're using the information that other people gave them? Make sense?

Ok.

The second set of questions concern scientific facts.

(2a) What is meant by a fact in science?

A fact is something that has been proven and you know it to be true.

(2b) Give me an example of a scientific fact.

Ah... [pause] Ok there's air in this room! [laughs]

(2c) What makes this fact scientific?

I guess it had to be proven. It wasn't just accepted - it had to be figured out, analyzed and observed - if you want to say that.

(2d) How do you think it was obtained?

People's minds started wondering. I think it's typical of humans that they kind of want to know why things are the way they are so I guess a cave man or someone sat around and said "gee I wonder what this we are breathing," and started to figure it out

(2e) Are scientific facts open to question?

Definitely!

Why?

Well you know they used to believe, take it as a fact that the earth was the center of the universe then they proved that it's not.

Now I'm going to move away from facts and into theories.

(3a) What is meant by a theory?

Ah... it's something that someone used their thinking and probably experiments and things to come up with something to explain something that was previously not understood but I guess it's not really completely proven because it's not a fact but a theory. They believe it's true but there's really no way to prove it 100%

(3b) Give me an example of a theory.

The theory of relativity.

(3c) How do you know this is a theory?

Because it's called the theory of relativity! [laughs] When Einstein came up with it there were still people who didn't believe it even though he did.

(3d) What is the purpose of theories? Why are they used

They are used to try to explain things. To try to put on paper or put into focus if you want ah... again why things are the way they are.

(3e) What is the difference between a theory and a fact?

A theory is not completely proven and taken as true whereas a fact isn't questioned.

(3f) Would it be more accurate to say that theories are models or that they describe the world as it is?

I think they're models.

Why?

Because they can be proven or disproven. They're ... when people go to study a certain thing, if there's already a theory there that's what they use as a kind of a base. They don't just take that to be true and if they don;t believe that it is true then they'll try to disprove it or come up with a better one but if it was a fact they wouldn't they'd just accept it

(3g) Do theories ever change?

Uh hum.

How?

Well, new information, different people. Like, for example if you've got a scientist who's really respected and people come and start to think of him as perfect and that anything he says is right well if he comes up with a theory people might just believe it because they have so much faith in him and then 100 years down the road someone else might come along and say "Hey this is not right!" and show a good reason for it then the theory would change, right?

(3h) Is there such a thing as a weak theory vs. a strong theory or can there be only one theory at any given time?

Definitely. Anyone can come up with a theory. I can say now ... I can come up with a theory right now and it might be totally stupid [laughs] but you could have someone who could work on a theory for 25 years and it could make a lot of sense. It might even become a fact.

I want to talk about the last area now. It's all about a thing called a scientific law.

(4a) What is meant by a scientific law?

I guess it would be a [pause] something that is just followed; it's just believed in. Like the law of gravity. It's almost like a fact.

My next question was "Give me an example of a law." You've just done that so I'll move on.

(4c) Why is this a law?

I don't really know that one but ah... it's almost like my answer for a fact I guess because it's just believed in. People just don't dare cross the line I guess! [laughs]

(4d) How did this become a law?

The law of gravity?

(Nod)

Well I guess it was developed and people believed in it and stated that it was a fact and they just made it a law. Now all scientists believe it er they have to I guess. [laughs] It's confusing. I can't really find the words

Imagine if you were trying to write this down.

I find it easier to write it down ... definitely.

(4e) What is the difference between a law and a theory?

Um Well I guess a law wouldn't ... they wouldn't try as hard to change it. Again a law is not really a model and um where a theory you change the theory and a law you just add another line. Make sense?

Can you distinguish between a law and a fact?

Well ... [pause] ... a fact is ... [pause] ... just words that just accepted as explaining something whereas a law is telling you what to do and what not to do, what to believe in and what not to believe in. It becomes a difference because a fact is a statement and a law is more of ... almost a command.

(4f) Why do we have laws in science?

... [pause] ... I guess so scientists will use their abilities in the right direction. You know like if they didn't, for example using the law of gravity again. If they assumed it wasn't true and tried to prove it well they're not gonna do that because of how it has been proven so they're just going to have to accept that's true.

(Conclude Interview)

Subject: Male
School: Large All-Grade School in Large Community
Group: (D)--Non-Academic Non-Science

I'm going to ask you four general questions and each one will have seven or eight separate parts to it. The first question concerns the way in which science proceeds.

(1a) What is science?

To me science is the study of the earth and the environment. Living things on the earth.

(1b) What does it involve doing?

Well we did a lot of study about the human body, nature, plants and animals and food chains.

So what kinds of stuff would scientists do as they went about their business?

Well they would get things, say a plant for example, and they'd study it and figure out which part is which and try and explain it so future people could learn what the thing was about.

(1c) What makes science different from other things?

It's harder. It's interesting too.

How could you tell science apart from history, geography and other areas of study?

Science is mainly with the earth type of thing. Geography is about places on the earth.

(1d) How do scientists know what to do? In other words, what influences scientists to undertake whatever projects they are currently working on?

Interest.

Is there anything besides interest?

Nothing that I know of.

(1e) What is a scientific method?

I don't know really.

Let me just give you that question another way. If a scientist had a problem that he or she wanted to do, how would he or she approach the problem?

Well if they were working with say a cancer patient they would probably try and get the cancerous spot out then they would start doing different tests to try and figure out how to cure or control it.

(1f) What is the role of observation in science?

Well in some cases they have say one or two cases and in some cases sometimes more and they would do a certain thing to each sample and one sample left alone without anything added to it. They would just look and see what different ah... things that's happened to the one with nothing done to it and the one with something done to it.

(1g) How does science change from year to year?

Science changes with different changes of the earth. New diseases coming up they've got to try and figure new ways of curing or controlling it.

The second set of questions concern scientific facts.

(2a) What is meant by a fact in science?

A scientific fact to me is something that has been proven to be true.

(2b) Give me an example of a scientific fact.

[pause] No I don't really think I can.

Well you know that for magnets, unlike poles attract.

(2c) What makes this fact scientific?

Well it has been proven that north would attract south because [pause] well I don't really know how.

Other than being proven, is there anything that makes it scientific?

Not to my knowledge.

(2d) How do you think it was obtained?

I think scientific facts were obtained by doing experiments and say like ah... cancer, someone is doing something about cancer, trying to cure or control it. So far it has been proven that there is no cure but there have been experiments done.

(2e) Are scientific facts open to question?

Yes I believe they are.

Why?

Because [pause] some day in the future we probably will get a cure for cancer or AIDS and hopefully we will.

Now I'm going to move away from facts and into theories.

(3a) What is meant by a theory?

It's just an idea that such and such a thing is incurable but maybe after testing it may be proven that the theory was wrong.

(3b) Give me an example of a theory.

A theory could probably be that trees are green.

(3c) How do you know this is a theory?

Just look at the trees and tell that they are green. But you might do some testing and find that they might be some other color besides green.

(3d) What is the purpose of theories? Why are they used?

A theory could be used to help a scientist at his project. What's the other part of the question?

How are they used? Well it's much the same question and I think you've answered it.

(3e) What is the difference between a theory and a fact?

A fact is something which has been proven and a theory is something which has not been proven.

(3f) Would it be more accurate to say that theories are models or that they describe the world as it is?

A theory could be probably when it describes the world as it really is.

What makes you think that?

Well it's like I was saying about the trees a few minutes ago. They look green but when you look at them under the microscope you might see different colors.

(3g) Do theories ever change?

Yeah they change. You might do a test on your theories like the trees and when you get the testing done you might find that there's not just green but there's black and brownish colors to it.

(3h) Is there such a thing as a strong theory or a weak theory or can there be only one theory at any given time?

Probably there is. I'm not sure.

Could you maybe think of an example?

A strong theory could be steel is hard and a weak one could be that steel is soft.

What would be the difference?

Well everybody knows that steel is hard but there is some soft steel I suppose. It depends on the carbon.

I want to talk about the last area now. It's all about a thing called a scientific law.

(4a) What is meant by a scientific law?

To me a scientific law is something which has been proven beyond the shadow of a doubt.

(4b) Give me an example of a law.

I don't recall any laws right now.

How about newton's third law of motion, action and reaction, or Newton's law of universal gravitation. Have you ever heard of either one of those?

The law of action and reaction.

(4c) Why is this a law?

It's a law because it has been proven. For example if you bounce a ball off the wall, it'll come back.

(4d) How did this become a law?

It has been proven beyond the shadow of a doubt that when you push down on the desk it's giving off more than you're putting into it so you can't push it down right?

(4e) What is the difference between a law and a theory?

A theory is something that has not been proven but could be proven true or false. A law is something that has been proven.

Would you be able to distinguish between a law and a fact?

A fact is something that has been proven but is questionable but a law is something that has been proven.

(4f) Why do we have laws in science?

I think we have laws in science because some scientists can help each other by proving certain things. Say one scientist has one thing he could say is a law but another scientist has something else. They could get together and work out something to prove it is a law.

(Conclude Interview)

Appendix C

Conceptual Inventories

Subject: Academic Science #1

Science involves explanation.

Scientists are motivated by interest.

Scientists are motivated by curiosity.

Scientists observe deliberately to obtain data and observe in general to obtain inspiration.

Science changes as advances in technology make it easier to obtain data.

Science changes as more and more information is added to the knowledge base.

Scientific facts are obtained by experimentally testing hypotheses.

Scientific facts are open to question but are in all likelihood correct.

A theory is a possible but not proven explanation.

Theories can be proven true.

Theories may be disproven.

Theories are assumed to be exact descriptions of what is happening.

Only one theory is widely accepted at any particular point.

Laws are proven facts or procedures.

Laws consolidate science by providing a stable knowledge base.

Subject: Academic Science #2

Science generally involves obtaining explanations.

Science is dynamic; it is subject to change.

Scientific facts are tentative.

Scientists are motivated by curiosity.

A scientific method involves research.

Open minded observation can yield unexpected but useful results.

Science changes in response to societal needs.

Scientific information is becoming more precise with time.

Scientific facts are not really open to question.

Theories are possible but not proven explanations.

Theories stimulate further research in science.

Theories are models because they are tentative.

Theories can be proven as fact.

Several different theories can explain the same event.

A law is a statement of expected behavior.

Laws are proven and have withstood the test of time.

Laws explain phenomena.

Subject: Academic Science #3

Science involves explaining natural phenomena.

Science involves explaining artificial occurrences.

Science does not exist by itself; it is a product of human intelligence.

A scientific method is a stepwise solution to a problem.

Scientists observe deliberately to gather data.

Science changes as man's perceptions change.

Scientific facts arise from experiment.

Scientific facts are tentative.

Theories are possible but not proven explanations.

Theories are used to communicate ideas and concepts.

Theories are models because they are tentative.

There may be several theories competing at any given time because people may have different perspectives.

Scientific laws are absolute statements of truth.

Scientific laws are arrived at through induction.

Laws are used to check the validity of experimental results.

Subject: Academic Science #4

Science is the process of explanation.

Science deals in exactness.

Scientists are motivated by curiosity.

Scientists observe deliberately to gather data.

The scientific method involves planning, setting objectives and the analysis of information.

Science changes as people improve on methods.

Science is continually improving.

Scientific information is derived from experiment.

Scientific facts are open to question as there is always the possibility that the method by which they were obtained may be flawed.

Theories are possible but not proven explanations.

Theories function as building blocks upon which further research is based.

Theories may one day become fact.

Theories are models because they are tentative.

It is reasonable to have more than one theory.

Scientific laws are absolute statements of truth.

Laws are proven.

Laws guide scientists by defining accepted procedures.

Subject: Academic Science #5

Science involves the study of life and its inter-relationships with the environment.

Science involves experiments and personal involvement with the items to be studied.

Other subjects are derived from science.

Scientific research tends not to be original.

A scientific method involves formulas, labs, and personal involvement with the objects to be studied.

Scientists observe to obtain deep and personal understanding of phenomena.

Science changes by becoming more sophisticated.

Despite its sophistication, science is understandable.

Scientific facts are not really questionable.

Theories guide research.

Theories can be realistic or models.

More than one theory can explain the same event.

Theories can become law.

A law is a mandated research procedure.

Laws are proven.

Subject: Academic Science #6

Science involves study in areas traditionally termed scientific.

Science is creative.

Science is relevant to everyday life.

Scientists are motivated by curiosity.

Scientists are motivated by job duty.

Scientists respond to societal problems.

A scientific method involves detailed investigation.

Change in science is closely linked with technological change.

As science changes, it more and more approximates truth.

Scientific facts are proven.

Scientific facts are open to question as viewpoints are apt to change with different societal demands.

Theories are possible but not proven explanations.

Theories may one day become fact.

Theories are models because they are tentative.

As models, theories can help us understand the world.

Theories are open to change as societal values changes.

The difference between a strong or a weak theory is a personal one.

Laws are proven theories.

Laws consolidate science.

Subject: Academic Science #7

Science involves explaining natural phenomena.

Science involves explaining artificial phenomena.

Scientists are motivated by curiosity.

Science is based on experimentation and observation.

Scientists observe deliberately to obtain specific information.

Scientific facts arise from experimentation and observation.

Scientific facts are tentative because individuals always have the right to believe or disbelieve information.

Theories are possible but not proven explanations.

Theories guide scientific research.

Theories are models because models facilitate study.

Theories are tentative because they are not proven.

There may be several theories competing at any given time because people may have different perspectives.

Laws are procedures that must be followed.

Laws are proven true.

Laws unify science by ensuring that similar procedures are followed.

Subject: Academic Science #8

Science involves explanation in general.

Scientists are motivated by previous research.

Scientists are motivated by challenging tasks.

Scientists observe deliberately to gather data.

Science changes by becoming more complex.

Scientific facts are obtained through research.

Scientific information is open to question because what is perceived as truth may be only so as current techniques are not advanced enough to disprove it.

Theories are possible but not proven explanations although there may be a certain amount of evidence behind them.

Theories are used to question things.

Several different theories can explain the same event.

Theories may become fact.

Theories are models because they are tentative.

Laws are statements of expected behavior.

Laws are proven.

Laws consolidate scientific knowledge and set directions for future research.

Subject: Non-Academic Science #1

Science involves experimentation and the obtaining of new information.

Science involves explaining phenomena.

Scientists are motivated by curiosity.

A scientific method is crucial for the success of an experiment.

Scientists observe deliberately to gather data.

Science changes generally as society changes.

Scientific facts are tentative but still unlikely to change.

Scientific facts are obtained through experiment.

A theory is a possible but not proven explanation.

Theories stimulate thought.

Theories can be proven or disproven.

More than one theory can explain the same event.

A law is a fact proven by induction.

Laws are mandated procedures.

Subject: Non-Academic Science #2

Science involves studying phenomena.

Much science is applied in a practical way.

Science is always changing.

Scientists obtain motivation from their educational background and from interest.

Scientists are motivated by possible practical applications of knowledge.

A scientific method involves hypothesizing, testing of theories through experiment and further modification of ideas if necessary.

Scientists observe deliberately to gather data.

Science changes as theories become more complex.

Scientific facts are obtained through experiment.

As science progresses, it becomes easier to prove ideas.

Scientific facts are tentative.

A theory is a possible but not proven explanation.

More than one theory can explain the same event.

Theories can be proven or disproven.

Theories are used to explain and communicate ideas.

Theories are models.

A law is a proven fact or theory.

Laws are used to explain.

Laws consolidate science by providing a factual basis.

Subject: Non-Academic Science #3

Science is the study of our world.

Scientists work simply to obtain new information.

Science reacts to societal problems.

A scientific method involves a systematic, problem solving approach.

Scientists observe deliberately to gather data.

Science is cumulative; new information illuminates old.

Theories are possible but not proven explanations.

Theories may be used to generate yet more theories; to provide building blocks upon which further research is based.

Theories are models.

Several different theories can explain the same event.

Laws have been proven and are universally accepted.

Laws consolidate scientific knowledge and set directions for future research.

Subject: Non-Academic Science #4

Science involves explanation.

Scientists are motivated by personal interest.

A scientific method involves research in a planned investigation.

Scientific facts are obtained through research and experiment.

Scientific facts are tentative.

A theory is a person's idea.

Theories explain science.

The degree of universal agreement separates theory from fact and theory from law.

Theories are models because they are tentative.

A law is a known fact.

Subject: Non-Academic Science #5

Science involves explaining phenomena.

Science is based on experiment.

Scientific facts are proven.

Scientists are motivated by curiosity.

Scientists also base research upon recognized societal needs.

A scientific method involves experimenting.

Scientific observation provides the basis for fact.

Scientific change may be revolutionary.

Detail is added as science progresses.

Scientific facts are tentative in some instances. They also may be absolute [proven].

Theories are possible but not proven explanations.

Theories can be changed.

Theories are used both to communicate and to guide future research

Theories are models because they are tentative.

There may be several theories competing at any given time because people may have different perspectives.

Laws consolidate scientific knowledge.

Subject: Non-Academic Science #6

Science involves explanation of p nomena.

Science is a broad area.

The study of science involves little room for personal opinion.

Scientists understand our environment.

Scientists are motivated by personal interest.

Scientists react to society's needs.

A scientific investigation involves a planned, stepwise investigation.

Scientists observe in order to relate the observations to others as evidence.

Science changes as technology makes procedures and data collection easier.

Scientific facts are obtained through repeated experiment.

Scientific facts are tentative in that detail can be added.

A theory is a possible but not proven explanation.

Theories provide explanation.

Theories are realistic; they are not models because they do not stand for something.

More than one theory can explain the same event.

Theories can be proven to become law.

Laws are proven explanations.

Subject: Non-Academic Science #7

Science involves explaining phenomena.

Scientists are motivated by curiosity

Scientists are motivated by financial rewards.

Science changes as information gathering procedures change with advancing technology.

Scientific facts are obtained through experiment.

Scientific facts are not absolute.

Theories are possible but not proven explanations.

Theories guide experiments.

Theories are models because actual phenomena is too complex to be accurately described.

Theories can change with time.

Laws evolve from theories that are proven.

Laws unify science.

Subject: Non-Academic Science #8

Science is a very broad area.

Science involves experiments, study and research.

Science is relevant to everyday life.

Scientists are motivated by ambition.

A scientific method involves research and lab work.

Observation is an integral part of the scientist's whole life.

Science constantly changes as previously accepted information is discredited.

Scientific information is tentative and quite open to change.

Theories are possible but not positive explanations.

Theories provide convenient explanations.

Theories are models because they provide workable explanations in lieu of the absolute truth.

More than one theory can explain the same event.

Simpler theories are preferable to more complex ones.

Laws are proven facts.

Laws provide workable explanations.

Subject: Academic Non-Science #1

Science involves explaining natural phenomena.

Science involves learning and applying concepts.

Science is a way of thinking.

Scientists are motivated by curiosity.

Scientists are motivated by societal needs.

A scientific method involves the applying of concepts and theorems.

Scientists observe at all times.

Science changes as more and more facts are accumulated.

Scientific knowledge accumulates as people react to perceived problems.

Scientific facts are tentative as, several times in the past, information has been discredited.

Theories are possible but not proven explanations.

Theories are used to communicate concepts.

Theories are models because they are tentative.

People may sometimes accept theories because of the proposer rather than because of the theory itself.

There may be several theories which explain a given phenomena.

Theories can become fact.

Laws are procedures that must be followed.

Laws set direction for future research.

Subject: Academic Non-Science #2

Science involves explaining natural phenomena.

Science is creative.

Science involves explaining artificial phenomena.

Scientists are motivated by curiosity.

A scientific method involves study, research and the application of scientific laws and formulas.

Scientists observe deliberately to obtain specific information.

Scientific facts arise from experimentation and observation.

Science changes as its practitioners become more advanced.

Scientific facts are open to question as people, out of curiosity, shall seek clarification.

Theories are possible but not proven explanations.

Theories describe the world as it is.

Theories may change as detail is added.

Laws consolidate explanation.

Subject: Academic Non-Science #3

Science involves study of everything in the universe.

Scientific investigation is dependent upon the availability of resources.

A scientific method involves experimentation, observation, hypothesizing and conclusion.

Scientists observe deliberately to obtain specific information.

Science changes as problems become more thoroughly investigated.

Scientific facts arise from experiment and observation.

Scientific information is open to question and can be made more accurate.

A theory is a proven fact.

Theories are used to answer questions and to explain.

Theories are realistic because they have been proven.

Theories do not change.

There can be only one theory at any given time because it has been proven.

Laws are practical statements formed from several theories.

Laws set directions for future research.

Subject: Academic Non-Science #4

Science involves obtaining information on living creatures.

Science involves obtaining information on the behavior of non-living things.

Science involves obtaining explanations.

A scientific method involves a planned experiment.

Scientists observe deliberately to gather data.

Science changes as more and more naive ideas are replaced by more rigorous ones.

Scientific facts are obtained from experiment and through the process of reasoning through known information.

Scientific facts are open to question as not all of them are complete.

Theories are possible but not proven explanations.

Theories are used to improve the human condition.

Theories are models because they are tentative.

There may be several theories competing at any given time because people may have different perspectives.

Scientific laws are absolute statements of truth.

Laws are obtained through induction.

Laws are used to check the validity of experimental results.

Subject: Academic Non-Science #5

Science involves obtaining information on a variety of subjects.

Science is a very broad area.

Scientists are motivated by curiosity.

Science is accumulative; scientists build upon the work of others.

A scientific method involves analyzation, observation and communication.

Scientists observe deliberately to gather data.

Science changes as more and more problems are solved.

Scientific facts are obtained through observation.

Scientific facts may be questioned, however unless it is a theory, the process is futile.

Theories are possible but not proven explanations.

Theories stimulate creative science.

Theories are models because they are tentative.

There may be several theories competing at any given time because people may have different perspectives.

Laws evolve from theories.

Laws furnish us with an accurate basis for future work.

Subject: Academic Non-Science #6

Science is man's curiosity and desire to learn.

Science involves experimentation and the obtaining of new information.

Science is a human activity.

Scientists are motivated by the constant improvement of the scientific knowledge base.

Scientists are motivated by society's needs.

Scientists are motivated by personal interest.

Scientists observe deliberately to gather data.

Science is dynamic; it is constantly changing.

Scientific facts are agreed on by the scientific community.

Scientific facts are tentative.

A theory is a possible but not necessarily proven explanation.

Theories guide future research.

Theories may be disproven.

Theories are models.

Theories can be true.

Theories can become law.

Laws are statements of truth which cannot be disproven.

Laws consolidate science by providing a factual knowledge base.

Laws guide research.

Subject: Academic Non-Science #7

Science involves explanation.

Science is creative.

Scientists are motivated by curiosity.

Scientists are motivated by external reasons.

Scientists observe to gather data.

Science changes as the information sought becomes more specific.

Scientific facts are obtained inductively through experiment.

Scientific facts are tentative because our understanding of the world is not complete enough to warrant complete confidence.

Theories are possible but not proven explanations.

Theories help people understand phenomena.

Theories could be either models or realistic.

There may be several theories competing at any given time because people may have different perspectives.

Laws are universally accepted statements of behavior.

Laws are proven inductively.

Laws consolidate previous research in order to facilitate new work.

Subject: Academic Non-Science #8

Science involves explaining natural phenomena.

Scientific facts are obtained through experimentation.

Scientific facts are more detailed than other forms of knowledge.

Scientists are motivated by curiosity.

A scientific method involves experimentation.

Scientists observe to gather data.

Science changes as it reacts to societal needs.

Scientific facts are proven.

Some scientific facts are tentative depending upon personal orientation.

Theories are possible but not proven explanations.

Theories assist in future research.

Theories are models because they are tentative.

Over time, theories become more accurate.

There may be several theories competing at any given time because people may have different perspectives.

Laws are mandated procedures.

Laws provide direction for future research.

Subject: Non-Academic Non-Science #1

Science involves explanation.

Scientists try to prove explanations.

Scientists are motivated by curiosity and previous research.

A scientific method is an experimental procedure.

Scientists observe to gather data for comparison to other experiments.

Science changes as more facts are accumulated.

Scientific facts are obtained and proven through experiments.

Some scientific facts are tentative; some are not.

A theory is a possible but not proven explanation.

Theories provide explanations of phenomena.

Theories are models because they are tentative.

Theories change as problems with existing theories are handled.

Theories may be disproven.

The process of changing theories takes time.

A law is a universally accepted statement of truth.

Laws furnish us with a factual base; they consolidate science.

Subject: Non-Academic Non-Science #2

Science involves the memorization of facts.

Science is relevant to daily life.

Scientists are motivated by curiosity.

Scientists are motivated by societal needs.

Scientific facts are learned from investigation in a lab setting.

Science changes as people become more sophisticated.

Science changes as technology permits more accurate answers and as people have a more developed knowledge base.

Scientific facts are cumulative.

Theories are possible but not proven explanations.

Scientific theories can become fact.

Theories are models because they are tentative.

Laws are procedures that must be followed.

Laws are proven and unquestionable.

Laws stimulate interest in research.

Subject: Non-Academic Non-Science #3

Science involves studying phenomena,

Science involves memorizing facts.

Scientists are motivated by curiosity.

Scientists are motivated by financial gain.

Scientists are motivated by societal needs.

Science changes as technology facilitates data gathering.

Scientific facts are proven and unquestionable.

Theories are possible but not proven explanations.

Scientific theories can become fact.

Scientific theories do not describe the world like it really is because they are not proven.

A scientific law is a procedure to follow.

A scientific law is like a fact.

Laws unify science by ensuring that similar procedures are followed.

Subject: Non-Academic Non-Science #4

Science involves explaining natural phenomena.

Science involves explaining artificial occurrences.

Science is relevant to everyday life.

Scientists are motivated by curiosity.

Science changes as society changes.

Science changes as society presents new problems.

Scientific facts are obtained from experiment.

Scientific facts are open to question as scientists may discover new directions for research.

Theories are possible but not proven explanations.

Theories facilitate the extraction of conclusions from experiment.

Theories describe the world as it is because they deal with life.

Theories can change as experiments change.

Laws are procedures that are followed.

Subject: Non-Academic Non-Science #5

Science involves explaining natural phenomena.

Scientists are motivated by curiosity.

Scientists observe deliberately to gather data.

Scientific facts are obtained through experimentation.

Scientific information is tentative because it will probably be improved upon by adding detail or additional information.

Theories are possible but not proven explanations.

Theories attempt to describe the world as it really is.

Theories may change if experience necessitates.

Scientific laws are absolute statements of truth.

Laws are proven.

Laws encourage cooperation among scientists.

Subject: Non-Academic Non-Science #6

Science involves studying phenomena.

Scientific facts are detailed.

Scientists are motivated by curiosity.

Scientists observe deliberately to gather data.

Science changes as more detailed facts are accumulated.

Scientific facts are obtained through research and experiments.

Scientific facts are tentative.

A theory is a possible but not proven explanation.

Theories are models because they are tentative.

Theories can be improved upon.

More that one theory can explain the same event.

Laws set guidelines for research.

Subject: Non-Academic Non-Science #7

Science involves in general the study of Earth.

Science helps society.

Scientists are motivated by curiosity.

Scientists are motivated by society's needs.

A scientific method involves experiments.

Scientists observe deliberately to gather data.

Science changes as methods become more advanced.

Scientific facts are obtained through experiments.

Laws are proven knowledge.

Laws provide a trustworthy factual base.

Subject: Non-Academic Non-Science #8

Science involves study.

A scientific method involves formulas and experiments.

Science changes by becoming generally broader.

Scientific facts are proven.

Scientific facts arise from investigation.

Some scientific facts are open to question.

Theories are possible but not necessarily proven explanations.

Theories may change.

Scientific laws are ideas that cannot be changed.

Scientific laws are arrived at inductively.

Scientific laws help prove new information.

Appendix D

Individualized Questionnaires

Subject: Academic Science #1

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science is unconcerned with explanation.

____ Scientists are not motivated by interest.

____ Scientists are motivated by curiosity.

____ Scientists observe deliberately to obtain data and observe in general to obtain inspiration.

____ Changes in science are unrelated to technology.

____ Science changes as more and more information is added to the knowledge base.

____ Scientific facts arise from experimentally testing hypotheses.

____ Scientific facts are open to question but are probably correct.

____ A theory is a proven explanation.

____ Theories can never be proven true.

____ Theories may be disproven.

____ Theories are not an exact descriptions of what is happening.

____ Only one theory is widely accepted as explaining a particular event at any particular point.

____ Laws are proven facts or procedures.

____ Laws consolidate science by providing a stable knowledge base.

Subject: Academic Science #2

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science generally involves obtaining explanations.

____ Science is static; it is not subject to change.

____ Scientific facts are proven and unquestionable.

____ Scientists are motivated by not curiosity.

____ A scientific method involves research.

____ Open minded observation can yield unexpected but useful results.

____ Science is unresponsive to societal needs.

____ Scientific information is becoming more precise with time.

____ Scientific facts are not really open to question.

____ Theories are proven explanations.

____ Theories stimulate further research in science.

____ Theories are models because they are tentative.

____ Theories can be proven as fact.

____ Several different theories can explain the same event.

____ A law is a statement of expected behavior.

____ Laws have not been proven and may not withstand the test of time.

____ Laws explain phenomena.

Subject: Academic Science #3

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science involves explaining natural phenomena.

____ Science involves explaining artificial occurrences.

____ Science does not exist by itself; it is a product of human intelligence.

____ A scientific method is a stepwise solution to a problem.

____ Scientists observe deliberately to gather data.

____ Science does not change as man's perceptions change.

____ Scientific facts arise from experiment.

____ Scientific facts are unquestionable.

____ Theories are proven explanations.

____ Theories are used to communicate ideas and concepts.

____ Theories are models because they are tentative.

____ There may be several theories competing at any given time because people may have different perspectives.

____ Scientific laws are absolute statements of truth.

____ Scientific laws are arrived at through induction; when enough examples are found to warrant trust in them, they are accepted as true.

____ Laws are used to check the validity of experimental results.

Subject: Academic Science #4

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science is the process of explanation.

____ Science deals in approximation; it is inexact.

____ Scientists are unmotivated by curiosity.

____ Scientists observe deliberately to gather data.

____ The scientific method involves planning, setting objectives and the analysis of information.

____ Science changes as people improve on methods.

____ Science is neither improving nor getting worse - it is static.

____ Scientific information is derived from experiment.

____ Scientific facts are open to question as there is always the possibility that the method by which they were obtained may be flawed.

____ Theories are proven explanations.

____ Theories are unrelated to further research.

____ Theories may one day become fact.

____ Theories are models because they are tentative.

____ It is reasonable to have more than one theory.

____ Scientific laws are absolute statements of truth.

____ Laws are not proven.

____ Laws guide scientists by defining accepted procedures.

Subject: Academic Science #5

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science involves the study of life and its inter-relationships with the environment.

____ Science involves experiments and personal involvement with the items to be studied.

____ Other subjects unrelated to science.

____ Scientific research is original.

____ A scientific method involves formulas, labs, and personal involvement with the objects to be studied.

____ Scientists observe to obtain deep and personal understanding of phenomena.

____ Science changes by becoming less sophisticated.

____ Science is not understandable.

____ Scientific facts are not really questionable.

____ Theories guide research.

____ Theories can be realistic or models.

____ Only one theory can explain a given event.

____ Theories can not become law.

____ A law is a mandated research procedure.

____ Laws have not been proven.

Subject: Academic Science #6

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science involves study in areas traditionally termed scientific.

____ Science involves little creativity.

____ Science is irrelevant to everyday life.

____ Scientists are motivated by curiosity.

____ Scientists are unmotivated by job duty.

____ Scientists respond to societal problems.

____ A scientific method involves research using random, unplanned investigation.

____ Change in science is unrelated to technological change.

____ As science changes, it more and more approximates truth.

____ Scientific facts are proven.

____ Scientific facts are unquestionable.

____ Theories are possible but not proven explanations.

____ Theories may one day become fact.

____ Theories are not models because they are proven.

____ Theories can help us understand the world.

____ Theories do not change as societal values change.

____ The difference between a strong or a weak theory is a personal one.

____ Laws are proven theories.

____ Laws consolidate science.

Subject: Academic Science #7

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science involves explaining natural phenomena.

____ Science involves explaining artificial phenomena.

____ Scientists are not motivated by curiosity.

____ Science is based on experimentation and observation.

____ Scientists observe deliberately to obtain specific information.

____ Scientific facts arise from experimentation and observation.

____ Scientific facts are not open to question.

____ Theories are proven explanations.

____ Theories hinder scientific research.

____ Theories are models because models facilitate study.

____ Theories are unquestionable because they are proven.

____ There may be several theories competing at any given time because people may have different perspectives.

____ Laws are procedures that must be followed.

____ Laws are possible but not proven true.

____ Laws unify science by ensuring that similar procedures are followed.

Subject: Academic Science #8

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science involves explanation in general.

____ Scientists are uninterested in previous research.

____ Scientists are motivated by challenging tasks.

____ Scientists observe deliberately to gather data.

____ Science changes by becoming less complex.

____ Scientific facts are obtained through research.

____ Scientific information is open to question because what is perceived as truth may be only so as current techniques are not advanced enough to disprove it.

____ Theories are possible but not proven explanations although there may be a certain amount of evidence behind them.

____ Theories are used to question things.

____ Several different theories can explain the same event.

____ Theories cannot become fact.

____ Theories are not models because they are proven.

____ Laws are statements of expected behavior.

____ Laws are proven.

____ Laws consolidate scientific knowledge and set directions for future research.

Subject: Non-Academic Science #1

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science involves experimentation and the obtaining of new information.

____ Science is not involved with explaining phenomena.

____ Scientists are not motivated by curiosity.

____ A scientific method is not necessary for the success of an experiment.

____ Scientists observe deliberately to gather data.

____ Science rarely changes as society changes.

____ Scientific facts are tentative but still unlikely to change.

____ Scientific facts are obtained through experiment.

____ A theory is a possible but not proven explanation.

____ Theories stimulate thought.

____ Theories can be proven or disproven.

____ Only one theory can explain a given event.

____ A law is a fact proven by induction (if enough examples are true then we assume truth always occurs).

____ Laws are procedures that people may or may not use.

Subject: Non-Academic Science #2

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science involves studying phenomena.

____ Very little science is applied in a practical way.

____ Science is static; it doesn't change.

____ Scientists obtain motivation from their educational background and from interest.

____ Scientists are not motivated by possible practical applications of knowledge.

____ A scientific method involves hypothesizing, testing of theories through experiment and further modification of ideas if necessary.

____ Scientists observe deliberately to gather data.

____ Science changes as theories become more complex.

____ Scientific facts are obtained through experiment.

____ As science progresses, it becomes more and more difficult to prove ideas.

____ Scientific facts are proven and unquestionable.

____ A theory is a proven explanation.

____ More than one theory can explain the same event.

____ Theories can be proven or disproven.

____ Theories are used to explain and communicate ideas.

____ Theories are not models; they are realistic descriptions of what is actually happening.

____ A law is a proven fact or theory.

____ Laws are rarely used to explain.

____ Laws consolidate science by providing a factual basis.

Subject: Non-Academic Science #3

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science is the study of our world.

____ Scientists work to obtain new information.

____ Science ignores to societal problems.

____ A scientific method involves a haphazard approach.

____ Scientists observe deliberately to gather data.

____ Science is cumulative; new information illuminates old.

____ Theories are proven explanations.

____ Theories may be used to generate yet more theories; to provide building blocks upon which further research is based.

____ Theories are not models; they represent the world as it is.

____ Several different theories can explain the same event.

____ Laws have been proven and are universally accepted.

____ Laws consolidate scientific knowledge and set directions for future research.

Subject: Non-Academic Science #4

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science involves explanation.

____ Scientists are unaffected by personal interest.

____ A scientific method involves research with a random, unplanned investigation.

____ Scientific facts are obtained through research and experiment.

____ Scientific facts are proven and unquestionable.

____ A theory is a person's idea.

____ Theories explain science.

____ The degree of universal agreement separates theory from fact and theory from law.

____ Theories are not models because they are proven.

____ A law is a known fact.

Subject: Non-Academic Science #5

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science involves explaining phenomena.

____ Science is based on experiment.

____ Scientific facts are not proven.

____ Scientists are not motivated by curiosity.

____ Scientists often base research upon recognized societal needs.

____ A scientific method involves experimenting.

____ Scientific observation provides no basis for fact.

____ Scientific change is never sudden.

____ Detail is added as science progresses.

____ Scientific facts may be absolute (proven).

____ Theories are proven explanations.

____ Theories cannot be changed.

____ Theories are used both to communicate and to guide future research

____ Theories describe the world as it is because they are proven.

____ There may be several theories competing at any given time because people may have different perspectives.

____ Laws consolidate scientific knowledge.

Subject: Non-Academic Science #6

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science involves explanation of phenomena.

____ Science is a narrow area of study; it is not broad.

____ The study of science provides much room for personal opinion.

____ Scientists do not understand our environment.

____ Scientists are motivated by personal interest.

____ Scientists are unresponsive to society's needs.

____ A scientific investigation involves research with a planned, stepwise investigation.

____ Scientists observe in order to relate the observations to others as evidence.

____ Technology has no affect on changes in science.

____ Scientific facts are obtained through repeated experiment.

____ Scientific facts are tentative in that detail can be added.

____ A theory is a proven explanation.

____ Theories provide explanation.

____ Theories are realistic; they are not models because they do not stand for something.

____ More than one theory can explain the same event.

____ Theories can be proven to become law.

____ Laws are proven explanations.

Subject: Non-Academic Science #7

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ **Science involves explaining phenomena.**

____ **Scientists are motivated by curiosity**

____ **Scientists are not motivated by financial rewards.**

____ **Science changes as information gathering procedures change with advancing technology.**

____ **Scientific facts are obtained through experiment.**

____ **Scientific facts are absolutely proven.**

____ **Theories are proven explanations.**

____ **Theories are unrelated to experiments.**

____ **Theories are models because actual phenomena is too complex to be accurately described.**

____ **Theories do not change with time.**

____ **Laws evolve from theories that are proven.**

____ **Laws unify science.**

Subject: Non-Academic Science #8

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science is a very narrow area of study.

____ Science involves experiments, study and research.

____ Science is not relevant to everyday life.

____ Scientists are not motivated by ambition.

____ A scientific method involves research and lab work.

____ Observation is an unimportant part of the scientist's life.

____ Science constantly changes as previously accepted information is discredited.

____ Scientific information is tentative and quite open to change.

____ Theories are possible but not positive explanations.

____ Theories provide convenient explanations.

____ Theories are models because they provide workable explanations in absence of the absolute truth.

____ Only one theory can explain a given event.

____ Complex theories are preferable to simpler ones.

____ Laws are proven facts.

____ Laws provide workable explanations.

Subject: Academic Non-Science #1

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science involves explaining natural phenomena.

____ Science involves learning and applying concepts.

____ Science is a way of thinking.

____ Scientists are motivated by curiosity.

____ Scientists are detached from and unmotivated by societal needs.

____ A scientific method involves the applying of concepts and theorems.

____ Scientists observe only occasionally.

____ Science changes as new knowledge replaces old; previous facts are unimportant.

____ Scientific knowledge accumulates as people react to perceived problems.

____ Scientific facts are proven and unquestionable.

____ Theories are proven explanations.

____ Theories are used to communicate concepts.

____ Theories are not models because they are proven.

____ People may sometimes accept theories because of the proposer rather than because of the theory itself.

____ There may be several theories which explain a given phenomena.

____ Theories can never become fact.

____ Laws are procedures that must be followed.

____ Laws set direction for future research.

Subject: Academic Non-Science #2

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science involves explaining natural phenomena.

____ Science is not creative.

____ Science involves explaining artificial phenomena.

____ Scientists are motivated by curiosity.

____ A scientific method involves study, research and the application of scientific laws and formulas.

____ Scientists observe deliberately to obtain specific information.

____ Scientific facts arise from experimentation and observation.

____ Science changes as its practitioners become more advanced.

____ Scientific facts are open to question as people, out of curiosity, shall seek clarification.

____ Theories are proven explanations.

____ Theories are models; they describe the world as it is.

____ Theories may not change.

____ Laws consolidate explanation.

Subject: Academic Non-Science #3

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science involves study of everything in the universe.

____ Scientific investigation is independent of the availability of resources.

____ A scientific method involves experimentation, observation, hypothesizing and conclusion.

____ Scientists observe deliberately to obtain specific information.

____ Science changes as problems become more thoroughly investigated.

____ Scientific facts arise from experiment and observation.

____ Scientific information is unquestionable and completely accurate.

____ A theory is a proven fact.

____ Theories are used to answer questions and to explain.

____ Theories are realistic because they have been proven.

____ Theories change.

____ There can be only one theory at any given time because it has been proven.

____ Laws are practical statements formed from several theories.

____ Laws set directions for future research.

Subject: Academic Non-Science #4

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science involves obtaining information on living creatures.

____ Science involves obtaining information on the behavior of non-living things.

____ Science is unconcerned with obtaining explanations.

____ A scientific method involves a planned experiment.

____ Scientists observe deliberately to gather data.

____ Science changes as more and more naive ideas are replaced by more rigorous ones.

____ Scientific facts are obtained from experiment and through the process of reasoning through known information.

____ Scientific facts are complete and unquestionable.

____ Theories are proven explanations.

____ Theories are used to improve the human condition.

____ Theories are not models because they are proven.

____ There may be several theories competing at any given time because people may have different perspectives.

____ Scientific laws are suggested explanations.

____ Laws are obtained through induction (if enough examples are found then it is reasoned that the explanation must be true always).

____ Laws are used to check the validity of experimental results.

Subject: Academic Non-Science #5

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science involves obtaining information on a variety of subjects.

____ Science is a very narrow area.

____ Scientists are motivated by curiosity.

____ Scientists are unable to use the work of others.

____ A scientific method involves analyzation, observation and communication.

____ Scientists observe deliberately to gather data.

____ Science changes as more and more problems are solved.

____ Scientific facts are obtained through observation.

____ Scientific facts may be questioned, however unless it is a theory, the process is futile.

____ Theories are proven explanations.

____ Theories impede creative science.

____ Theories are models because they are tentative.

____ There may be several theories competing at any given time because people may have different perspectives.

____ Laws evolve from theories.

____ Laws furnish us with an accurate basis for future work.

Subject: Academic Non-Science #6

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science is man's curiosity and desire to learn.

____ Science involves experimentation and the obtaining of new information.

____ Science is not a a normal human activity.

____ Scientists are motivated by the constant improvement of the scientific knowledge base.

____ Scientists are not motivated by society's needs.

____ Scientists are not motivated by personal interest.

____ Scientists observe deliberately to gather data.

____ Science is static; 't stays the same.

____ Scientific knowledge does not need the agreement of the scientific community.

____ Scientific facts are proven and unquestionable.

____ A theory is a proven explanation.

____ Theories guide future research.

____ Theories may be disproven.

____ Theories are models.

____ Theories can be true.

____ Theories can become law.

____ Laws are statements of truth which cannot be disproven.

____ Laws consolidate science by providing a factual knowledge base.

____ Research is not guided by laws.

Subject: Academic Non-Science #7

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science involves explanation.

____ Science is creative.

____ Scientists are unmotivated by curiosity.

____ Scientists are unmotivated by external reasons.

____ Scientists observe to gather data.

____ Science changes as the information sought becomes more specific.

____ Scientific facts are obtained inductively through experiment.

____ Scientific facts are unquestionable because our understanding of the world is complete enough to warrant complete confidence.

____ Theories are possible but not proven explanations.

____ Theories prevent people from understanding phenomena.

____ Theories could be either models or realistic.

____ There may be several theories competing at any given time because people may have different perspectives.

____ Laws are universally accepted statements of behavior.

____ Laws are proven when enough instances warrant confidence in them.

____ Laws consolidate previous research in order to facilitate new work.

Subject: Academic Non-Science #8

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science does not involve explaining natural phenomena.

____ Scientific facts are obtained through experimentation.

____ Scientific facts are less detailed than other forms of knowledge.

____ Scientists are not motivated by curiosity.

____ A scientific method involves experimentation.

____ Scientists observe to gather data.

____ Science changes as it reacts to societal needs.

____ Scientific facts are proven.

____ Some scientific facts are tentative depending upon personal orientation.

____ Theories are possible but not proven explanations.

____ Theories impede future research.

____ Theories are not models because they are proven.

____ Over time, theories become less accurate.

____ There may be several theories competing at any given time because people may have different perspectives.

____ Laws are mandated procedures.

____ Laws provide direction for future research.

Subject: Non-Academic Non-Science #1

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science does not involves explanation.

____ Scientists try to prove explanations.

____ Scientists ignore previous research.

____ A scientific method is an experimental procedure.

____ Scientists observe to gather data for comparison to other experiments.

____ Science changes as more facts are accumulated.

____ Scientific facts are obtained and proven through experiments.

____ Some scientific facts are tentative (questionable); some are not.

____ A theory is a proven explanation.

____ Theories provide explanations of phenomena.

____ Theories are not models because they are proven.

____ Theories change as problems with existing theories are handled.

____ Theories may be disproven.

____ The process of changing theories is rapid.

____ A law is a universally accepted statement of truth.

____ Laws furnish us with a factual base; they consolidate science.

Subject: Non-Academic Non-Science #2

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science involves the memorization of facts.

____ Science is unrelated to daily life.

____ Scientists are motivated by curiosity.

____ Scientists are motivated by societal needs.

____ Scientific facts are learned from investigation in a lab setting.

____ Science changes as people become more sophisticated.

____ Science changes as technology permits more accurate answers and as people have a more developed knowledge base.

____ Scientific facts are not based upon previous work.

____ Theories are proven explanations.

____ Scientific theories can become fact.

____ Theories are models because they are not proven.

____ Laws are procedures that must be followed.

____ Laws are proven and unquestionable.

____ Laws reduce interest in research.

Subject: Non-Academic Non-Science #3

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science involves studying phenomena.

____ Science involves memorizing facts.

____ Scientists are unmotivated by curiosity.

____ Scientists are unmotivated by financial gain.

____ Scientists are unmotivated by societal needs.

____ Science changes as technology facilitates data gathering.

____ Scientific facts are proven and unquestionable.

____ Theories are proven explanations.

____ Scientific theories can become fact.

____ Scientific theories do not describe the world like it really is because they are not proven.

____ A scientific law is a procedure to follow.

____ A scientific law is like a fact.

____ Laws unify science by ensuring that similar procedures are followed.

Subject: Non-Academic Non-Science #4

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science does not involve explaining natural phenomena.

____ Science involves explaining artificial occurrences.

____ Science is relevant to everyday life.

____ Scientists are not motivated by curiosity.

____ Science changes as society changes.

____ Science changes as society presents new problems.

____ Scientific facts are not obtained from experiment.

____ Scientific facts are open to question as scientists may discover new directions for research.

____ Theories are proven explanations.

____ Theories help scientists obtain conclusions from experiments.

____ Theories describe the world as it is because they deal with life.

____ Theories cannot change.

____ Laws are procedures that are followed.

Subject: Non-Academic Non-Science #5

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science involves explaining natural phenomena.

____ Scientists are unmotivated by curiosity.

____ Scientists observe deliberately to gather data.

____ Scientific facts are obtained through experimentation.

____ Scientific information is unquestionable and proven.

____ Theories are proven explanations.

____ Theories attempt to describe the world as it really is.

____ Theories may change.

____ Scientific laws are absolute statements of truth.

____ Laws are proven.

____ Laws encourage cooperation among scientists.

Subject: Non-Academic Non-Science #6

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science involves studying phenomena.

____ Scientific facts are very general; not detailed.

____ Scientists are not motivated by curiosity.

____ Scientists observe deliberately to gather data.

____ Science changes as more detailed facts are accumulated.

____ Scientific facts are obtained through research and experiments.

____ Scientific facts are proven and unquestionable.

____ A theory is a proven explanation.

____ Theories are not models because they are proven.

____ Theories can be improved upon.

____ More that one theory can explain the same event.

____ Laws set guidelines for research.

Subject: Non-Academic Non-Science #7

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science involves in general the study of Earth.

____ Science does not help society.

____ Scientists are unmotivated by curiosity.

____ Scientists are motivated by society's needs.

____ A scientific method involves experiments.

____ Scientists observe deliberately to gather data.

____ Science changes as methods become less advanced.

____ Scientific facts are not obtained through experiments.

____ Laws are proven knowledge.

____ Laws provide a trustworthy factual base.

Subject: Non-Academic Non-Science #8

Indicate whether you agree or disagree with each of the following statements by placing an "A" or a "D" in the blank.

____ Science involves study.

____ A scientific method involves formulas and experiments.

____ Science changes by becoming generally narrower and more specific.

____ Scientific facts are not proven.

____ Scientific facts arise from investigation.

____ Scientific facts are unquestionable.

____ Theories are proven explanations.

____ Theories may change.

____ Scientific laws are ideas that cannot be changed.

____ Scientific laws are arrived at inductively.

____ Scientific laws help prove new information.