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ON ASSESSING ADOLESCENT UNDERSANDING OF THE NATURE OF SCIENCE

by

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Abstract

The research sought to qualitatively describe and analyze the beliefs of senior high school students in British Columbia about the nature of science. Secondly, it proposed a methodology for the evaluation of student understanding in this area. In defining 'understanding' it emphasized the cognitive aspect by identifying a knowledge and comprehension of the various positions within the philosophy of science as a major component. The study has analytical, empirical, and clinical interview components.

Two 'typologies' were developed which were based on the philosophical literature. They were an 'Empiricist view' and a 'Weltanschauungen view'. The typologies were used to generate differing patterns of responses to questions on the nature of science taken from the 1978 B.C. Science Assessment. Nine students were interviewed extensively on their reasons for making particular distractor choices and the transcripts were analyzed.

This analysis concluded that there was some evidence to support the construct validity of the typologies, and that they were useful in helping to identify the differing philosophical positions upon which the students based their answers to the questions on the nature of science.

It was further concluded that there was partial support for the suggestion that students' positions may be context dependent. Specifically, issues relating to science and its
methods tended to be answered within the framework of the 'Empiricist view' while questions related to the relationships between science and society were answered from a more Weltanschauungist perspective.

It was recommended that:

1. the typological analysis methodology developed would be helpful in constructing assessment instruments which measure a student's understanding of the nature of science from within the two generalized perspectives,
2. the differential response to the questions on science and its methods and those on science and society should be more thoroughly investigated, and
3. curriculum materials and strategies should be developed which address the understanding of the nature of science from the 'variety of perspectives' approach.
The Devil: Intellectual confusion may not be a Cardinal Sin, but it sure has brought us a lot of recruits.

-'Married', Act I, Scene 1
by Andrew Brotvick
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Chapter 1
The Problem

1.0 Introduction

The assessment of 'nature of science' has been a persistent problem in Science Education for the past two decades (Kimball (1968), Welch and Pella (1968), Mackay (1971), Schwirian (1968)). Recently, the various instruments used in the evaluation of this curricular objective have been subjected to severe criticism on various levels. This criticism has been aimed at their educational validity as well as their philosophical foundations. This thesis will review the relevant literature on the various tests (Test On Understanding Science, Nature of Science Scale, Nature of Science Test, Test on Understanding the Nature of Science, etc.), including both the educational and philosophical writings. This review is followed by the development of two philosophical 'views' of the nature of science against which adolescent's views may be seen in relief. The analysis of adolescent views in this manner provides preliminary and exploratory data for proposing the subsequent development of more philosophically defensible assessment instruments and approaches to measurement. It will be argued that such an assessment should take seriously what it means to meet the curricular objective of 'understanding the nature of science'. On this argument, students should not only have reflective awareness of their own position but also some familiarity with alternative views. This study limits itself to
an analysis of student understanding of their own position from the point of view of the philosophy of science. It is not a Piagetian study of the inner logic of the students. It concludes with proposals for an alternative approach to assessment in this area. The study is, therefore, an initial approximation of the directions in which I believe we should be heading.

2.0 Background And Rationale

The 'nature of science' objective has taken on a wide variety of definitions in the educational literature. Wagner and Lucas (1977) have narrowly defined an understanding of the 'nature of science' as the ability to "recognize the defining features of scientific inquiry, that is, its quest for objectivity, the tentativeness of solutions proposed, the nature of rules and types of evidence involved, canons of research protocol, and so forth." (Wagner and Lucas, 1977, p.549). Billeh and Malik (1977) define it more broadly as understanding science's "basic philosophy, its underlying assumptions, characteristics of the scientific enterprise, processes through which scientific knowledge is acquired and developed, and above all, the ethics of science." (Billeh and Malik, 1977, p.559). Broader still, Dunkee (1974) includes "knowledge of the social facets of natural science qua social institution or enterprise, knowledge of the vocational-sociological characteristics of scientists, and comprehension of the philosophical aspects of natural science and its processes." (Dunkee, 1974, p.343)

This diversity in defining the teaching content of the 'nature of science' does not, however, address the issue of the
underlying meaning of 'nature of science'. A prevailing assumption (Lucas, 1975) has been that the meaning of the 'nature of science' was clear. Reference to the philosophical literature clearly indicates that such is not the case.

Suppe (1977), in a thorough review of philosophical theories concerning the development and justification of scientific theories, demonstrates that there is a plurality of 'natures of science'. Some philosophers remain adherents of logical positivism, while others subscribe to one of a number of what Suppe calls the 'Weltanschauungen Analyses' which includes the positions of Kuhn, Popper, and Feyerabend among others. Finally, Suppe suggests that each of these schools are waning and will be subsequently replaced by philosophies of 'Historical Realism' as proposed by Lakatos, and refined by Toulmin and Shapere. As Lakatos (1970) has summarised the situation, "Watkins points out that the growth of science is inductive and irrational according to Hume, inductive and rational according to Carnap, non-inductive and rational according to Popper. But Watkins' comparison can be extended by adding that it is non-inductive and irrational according to Kuhn." (Lakatos, 1970, p.176). Brown (1977) has also devoted a book to the discussion of two general schools of philosophical belief. He argues that Logical Empiricism is definitely in decline but sees Suppe's Weltanschauungsists and Historical Realists as coalescing into 'The New Philosophy of Science'. He has taken on the task of elaborating the implicit epistemological assumptions of this coalition. It would appear then, that assumptions of the educational literature to the contrary, it cannot be said that
we have widespread agreement on the nature of science.

In the absence of a clear and uniformly agreed upon understanding of the nature of science, two educational problems result. Firstly, science curricula need to be revised to reflect this diversity. Some work has been done in this area (Aikenhead, 1976; Roberts and Orpwood, 1979). Secondly, the instruments and methods used to assess the understanding of the 'nature of science' need to be revised in such a way as to be able to report both a student's familiarity with a variety of possible views of science as well as their consistency within one preferred view. None of the existing instruments known to the author can satisfy either requirement.

The existing instruments have been criticised in the recent literature. On the conceptual level, Herron (1969) objects to their uni-dimensional nature. Most tests reflect one view of the nature of science and consequently can only report a student's level of agreement with that particular view. Given the variety of accepted views, it is inappropriate to rank student achievement on the nature of science objective according to how closely a student agrees with whichever view has been taken as the basis for the test. Students with differing views of science will obviously choose differing responses for a given question. For example, as Lucas (1975) indicates, in response to a TOUS item such as "it is important for a physicist to be able to throw away widely held ideas and think without restriction", an agree response would be most appropriate from a Popperian perspective while a Kuhnian response would more likely be to
disagree.

The deficiencies of the instruments at the conceptual level results in further criticism on the methodological level. As Aikenhead (1973) has pointed out, the reporting of a mean gain score on any of the existing tests is neither meaningful nor useful. Since the instruments are based upon a uni-dimensional conception of science, derived from a specific perspective, the gain measured by the test does not really reflect the diversity of what it means to understand the nature of science. Furthermore, if a student should change his or her perspective, no measure of this can be reported with any of the existing instruments. Aikenhead advocates a more qualitative treatment of test results, in particular, as formative feedback for curriculum development. Lucas (1975) criticises the tests' uni-dimensionality for covering up important differences in understandings. As he concludes from an analysis of Australian and Israeli students' responses to the same TOUS item, "The large differences in views about the aims of the scientific enterprise hidden in global scores are apparent." (Lucas, 1975, p.484).

Such criticisms of the instruments suggest that an alternative approach to testing the understanding of the nature of science is necessary. It is the purpose of this research to propose a new methodology for this area. The proposed methodology takes seriously the diversity of views of the nature of science by suggesting that we must begin to discover and describe the patterns of student beliefs about the nature of
science in relationship to these differing views. Assessment of learning in the area of nature of science would then consist in the comparison of student beliefs with those held by various philosophical schools. Creative item construction should be able to result in the construction of an instrument which delivers qualitative descriptions which could point out both a student's reflective awareness of one view as well as their knowledge of others. The present study emphasizes the former.

In seeking descriptions of the various viewpoints of science held by both students and academics, it is hoped that teachers will develop an appreciation of this diversity such that they can begin to devise and/or select appropriate materials and strategies for more effective instruction in the nature of science.

3.0 The Problem Of This Study

The central problem of this research is the qualitative description of the pattern of beliefs of Grade Twelve students of British Columbia with respect to the nature of science. It was hypothesized that students would ascribe to a variety of patterns of belief which are, at least in embryonic form, isomorphic with some of the belief patterns held by scientists and philosophers. One source of data for the study were the results of the 1978 B.C. Science Assessment.

In taking this assumption of patterns as a starting point, the author investigated firstly, the varieties or typologies of understanding the nature of science present in the philosophical literature; secondly, the variety of patterns of belief implicit
in the Scientific literacy items on the 1978 B.C. Science Assessment instrument; and thirdly, the percentage of students in B.C. who may be said to hold one of the resulting typologies. The problem may now be stated in the form of three questions:

1. Is there support in the literature, notably Suppe and Brown, for the construction of two generalized typologies of understanding the nature of science which can be utilized as a map against which student belief patterns can be charted?

2. Can evidence of such patterns be extracted, through informal content analysis, from the Science Assessment instrument which would generate two profiles of answer patterns?

3. What percentage of the Grade Twelve population of British Columbia can be said to hold either of the two profiles suggested, and what percentage hold neither of the consistent typologies described?

A meta-question weaves its way throughout this study. It critically questions the variety of methods used in the assessment of understanding. Formally stated, it asks:

4) Can methodological analysis of current practice lead to the foundations of a proposal for an alternative approach to the assessment of understanding which could produce the kind of qualitative information necessary for both classroom instruction and curriculum planning?
4.0 Definitions and Delimitations

As previously stated, the concept 'nature of science' can and does have a wide-ranging meaning in Science Education. For the purposes of this study, a conscious choice has been made in favour of limiting the definition to the cognitive realm of student attitudes. In this sense, the term includes knowledge of those factors cited by Dunkee previously: knowledge of 1) the social facets of natural science qua social institution, 2) the vocational-sociological characteristics of scientists, and 3) the philosophical aspects of natural science and its methods. Each of these factors can be described in terms of the social and cultural implications derived from each of the philosophical positions. It is assumed that the majority of Grade Twelve students will more easily be able to relate to such social and cultural aspects, rather than the more abstract philosophical issues. Consequently, it is these aspects which will be utilized in this study as a means of tapping the philosophical understandings of the students. In taking Dunkee's broader definition of the nature of science, recognition is given to the demands of the high school science curriculum objectives. These objectives specify that science students should be able to intelligently decide public issues of both the methods of science and resource allocation for scientific research as well as the application of the communicated results of scientific research in issues of social concern (Ministry of Education, 1969, p.4; 1970, p.6; 1977a, p.i; 1977b, p.1).

The data upon which this study is based are the results of
the British Columbia Science Assessment carried out in 1978. The assessment was part of the Provincial Learning Assessment programme and tested all students in Grades 4, 8, and 12 who were present in the schools on the day of the test.

In Chapter 4, two typologies will be presented. These typologies can be used to develop specific patterns of answers resulting from a content analysis of the Scientific Literacy items of the Science Assessment. It will be argued that each pattern forms part of a consistent philosophical approach to the nature of science. The content analysis of the stems and distractors of the Assessment instrument generated two such positions which, for the purposes of this thesis are called the 'Empiricist view' and the 'Weltanschauungist view'. While each typology is not entirely consonant with a particular philosophical position, they do fairly represent two of the general 'families' of beliefs. To this extent, belief in both was detectable in the population. The typologies formed the basis upon which the qualitative description of student beliefs was constructed.

Briefly stated, the 'Empiricist View' is based upon Suppe's and Brown's explication of the logical positivist position, with its associated derivatives and successors. Included here are the positions of philosophers such as Carnap, Nagel, and some interpretations of Popper. The 'Weltanschauungen view' falls within the broad interpretation espoused by Kuhn, Feyerabend, Lakatos, and some revised interpretations of Popper. The interpretation of Popper as a transitional philosopher is
largely derived from the work of Brown.

5.0 Overview Of The Study

Chapter Two reviews the literature in the area of nature of science to provide support for the qualitative rather than quantitative interpretation of 'nature of science' test results. Chapter Three provides the specific details of the study and the analytic procedures used in the analysis of the data. In addition, it provides the parameters of the population used for this study. Chapter Four outlines the proposed typologies used as the basis for the interpretation of the qualitative descriptions. Chapter Five presents the results of the three analyses; conceptual, empirical, and clinical. Chapter Six presents the conclusions and recommendations for further work.
Chapter 2

The Review Of The Literature

1.0 Introduction

While 'understanding of science' has become an influential curricular objective within the past two decades, interest in the measurement of attitudes towards and understanding of science has existed in the literature since the early 1920's (Welch and Fella, 1968; Champagne and Klopfer, 1977). With the curriculum boom of the 1960's, science education underwent a significant change in focus and orientation which resulted in there being almost universal agreement that serious effort should be devoted to the development of appropriate attitudes to science. Though the most recent assessment of science education in the United States (Stake and Easley, 1978) has surprisingly little to say on this topic, it has retained a significant level of support in Canada (Page, 1979). It is the purpose of this chapter to document the variety of instruments which have been created over the last two decades to measure these factors, review their current status, and offer a critique of their use. This review is foundational for the subsequent analysis of the requirements of a conceptual framework to utilize in the development of a new research protocol in the understanding of science.

2.0 The Traditional Instruments

A wide variety of instruments have been developed over the
past twenty years. This variety reflects the diversity on the part of educational researchers with respect to the appropriate emphasis to be taken in measuring understanding. Two general trends are noted in the literature. Firstly, the trend which began with the Test On Understanding Science, conceives the problem to be that of intellectually understanding the social, political and cultural constructions of scientific activity; the second trend is in the direction of a more affective and attitudinal approach to the understanding of science and scientists.

2.1 The Conceptual Instruments

2.1.1 Test On Understanding Science (TOUS)

Among the instruments which have been developed to investigate student understanding and attitudes, the most commonly used and widely known is the Test On Understanding Science. This instrument, developed by Cooley and Klopfer (1961), was designed for use as a research tool and was content validated by reference to a wide range of literature in philosophy of science, analysis of scientists at work, and the judgement of a large sample of practising scientists, science educators, historians and philosophers of science, among others. It was field tested, revised, and normalized during its preparation. In the ensuing 18 years, it has been utilized as a standard measure of understanding of science within the discipline. The test provides three subscale scores; one for an understanding about the scientific enterprise, one for an understanding of the scientist, and one for an understanding of the methods and aims of science. As a research instrument, it
has been widely used.

Despite its clear supremacy in this area, TOSUS has come under sharp criticism in recent years. Cronbach (1963) has taken the position that the lack of subscale scores on the elementary and junior high versions of the test is a problem. As he puts it: 'To agglomerate many types of post-course performance into a single score is a mistake, because failure to achieve one objective is masked by success in another direction.'

Wheeler (1968) has suggested that greater congruence between the subscales and Klopf's classification of aims for science education would be achieved if the number of subscales were reduced to two and were altered to reflect more directly the nature of scientific inquiry and the social aspects of science. Mackay (1971) used the instrument to measure understanding of science among junior high school students in Australia. His analysis of the results led him to conclude that common deficiencies existed in all three subscale areas. Specifically, he isolated as weaknesses the test's inadequate measurement of the following areas: 1) the role and influence of people and governments on science, 2) the contributions of past scientific findings, 3) the function of scientific societies, 4) the need for creativity in scientific research, 5) the honesty of scientists, 6) the relationship between experimentation, theories, models, and absolute truth, and 7) the interrelations between the sciences.

In working with the junior high school and elementary
versions (forms Jw and Ew) of TOUS, Fraser (1978) developed new items which yielded a different set of subscales, namely: a) Philosophical, b) Historical-Social, and c) Normality of scientists ratings.

Aikenhead (1973) in a review of many of the 'understanding of science' instruments points out that while TOUS is probably the most broadly documented, tested, and useful of the group, it suffers from some serious flaws. He says that the test is overly heavy on negative and stereotypic images and reports some evidence of the possibility of heavy loading on a verbal factor in factor analytic studies.

In a broader attack upon TOUS, Durkee (1974) partially agreeing with Mackay, decries the lack of items dealing with the following issues:

1) the distinctions and similarities between science and the humanities
2) types of scientific models, uses of models, relation of models to theory
3) perception versus conception
4) presuppositions of science
5) statistical versus deterministic aspects of science
6) objectivity versus subjectivity in science, bases of objectivity in science
7) nature of discovery
8) the distinction between deduction and induction
9) the manifestations of creativity in science, and
10) the dynamics of scientific revolutions.

2.1.2 Other Conceptual Instruments

While TOUS was the first of the modern instruments to be developed, many more have since been constructed. In most cases, they have arisen as a result of a perceived need for a test with a slightly different emphasis. In 1968 three tests were developed (the Science Process Inventory, the Nature of Science Scale, and the Nature of Scientific Knowledge Scale). This represented the beginnings of the differentiated conception of what was meant by 'understanding science' into the conceptual and the attitudinal domains.

In that year, the Science Process Inventory (SPI) was developed by Welch and Pella (1968). It too was based upon a model of understanding science derived from the writings of Beveridge, Connant, Kemeny, Lachman, Nash, and Wilson. Welch and Pella acknowledge the obvious in stating:

The SPI is based on the authority of a sample of scientists. As such, it may be valid for the opinion of this authority, but not valid for the opinion of all scientists. The controversial nature of the subject imposes restrictions on the validity of the instrument. (Welch and Pella, 1968, p.67)

Kimball (1968), in his work with the Nature of Science Scale (NOSS), takes as his starting point the philosophy of science espoused by Connant and Bronowski. Kimball's model of
the nature of science consists of eight assertions which are completely supported by both philosophers, and which draw subsidiary support from at least one other philosopher. The model itself was utilized to generate the 29 Likert-type items. Despite the affective format of the test, its content is conceptual rather than affective. As he predicted, philosophers score higher than both scientists and science teachers on this instrument. Ruba and Anderson (1978) proposed the Nature of Scientific Knowledge Scale (NSKS) which was based upon a further 'model of scientific knowledge' derived from Showalter (1974). The six factors of the NSKS model were: 1) amorality, 2) creativity, 3) developmental, 4) parsimony, 5) testability, and 6) unification.

2.2 The Attitudinal Emphasis

Researchers who adopted the attitudinal emphasis were not ignoring the conceptual level of understanding, but rather were attempting to separate the conceptual and attitudinal components. The tests with this emphasis, while including some with a purely affective orientation (such as the Science Support Scale), demonstrate the growing understanding that measurement in this area must become multi-dimensional.

The distinction between the conceptual and the attitudinal dimensions was the basis of work by Champlin (1970) in the development of The Beliefs About And Attitudes Toward Science And Scientists Scale (EATSS). Founded upon the work of Fishbein and Raven, Champlin constructed a scale which simultaneously measured beliefs about science as well as attitudes towards
science. A belief about science was defined as an expression of the *probability dimension* of an object's or concept's existence within the student, while an attitude towards science pertained to the *evaluative dimension* in respect of the object or concept about which the belief is held.

Moore and Sutman (1970) created the Scientific Attitude Inventory (SAI), which was intended to overcome their perception of the major flaws of the instruments discussed above. According to the authors, the SAI, unlike other instruments, met all four of the critical criteria for an attitudinal measure; namely,

1) preparation based upon specification of the particular attitude to be assessed
2) use several items to assess each attitude
3) provision for the respondent to indicate the extent of his acceptance or rejection of an attitude statement
4) concern with intellectual and emotional scientific attitudes.

A further five years passed before another major instrument was devised. Billeh and Zakhariades (1975) developed a 36-item test known as the Scientific Attitude Scale which was quickly followed by Kozlow and Nay's (1976) Test On Scientific Attitudes, a 40-item test split into a cognitive component and an intent component, and is therefore in the tradition of Champlin's earlier work. The TOSA was specifically created to sort out the problem of the lack of clear distinctions between the several dimensions of science which were being assessed.
Kozlow and May were pressing for a distinction between the cognitive and the affective components of attitudes towards science as well as a sorting out of the dimensional measures to be considered.

3.0 The Process Of Instrument Development

A reasonably consistent pattern has emerged in the development of each of the new instruments. Each one begins with the development of a model of 'understanding of science' most often based upon one or two influential philosophers of science or science educators. From this model, the instrument's author derives both the items and the answer key. At this point, the items are submitted to a panel of 'authorities' who pass judgement of each item's suitability as a measure of understanding science. After a pilot study for readability and comprehension, the test is further revised and field tested. There are two basic problems with this approach to evaluating understanding of science. Firstly, each instrument implicitly assumes that the discipline accepts, or should be willing to accept the stipulation of a specific understanding of the nature of science for test purposes. Secondly, it assumes that we are saying something of significance when we report numerical or gain-scores resulting from the administration of such tests to a specific population.

3.1 The Foundational Assumption Criticism

Connelly (1969) took the position that there was an inherent problem in using the available instruments for the evaluation of inquiry because each of the instruments embodies
within itself a particular view of inquiry. These inherent orientations prohibit the instrument's use in the evaluation of anything which is philosophically antithetical. In the same issue of the journal, Herron (1969) was posing a similar question by suggesting that implicit in the production of these instruments is the assumption that the discipline already understood the nature of science. But, he suggested:

We search the literature in science education, for the kind of scholarly debate which we know would be required to bring some specificity and precision to these conceptions. Unfortunately, such a debate has not been forthcoming. Detailed descriptions have tended to remain buried in the writings of a few individuals and seemingly not understood or patently avoided by almost everyone else. (Herron, 1969, p. 106)

He goes on to note that any concept as complex as the understanding of science must be capable of being seen from a variety of valid viewpoints. This being the case, the very foundations of the majority of the presently existing instruments are in serious danger.

Lucas (1975), goes further in criticizing these approaches to instrument construction when he complains that validation resulting from the consensus of various authorities is not justifiable. He says:

Unfortunately, a procedure of this type doesn't guarantee an adequate model of science. Firstly, it rests upon the methodological assumption that
consensus in the literature and among a panel, will produce the correct model. This is the "nine-out-of-ten-film-stars-can't-be-wrong" myth much beloved by soap advertisers. The myth probably results from the unjustified extension of the political principle, 'the majority rules', to an epistemological principle, 'the majority is right'. (Lucas, 1969, p.481)

3.2 The Analytical Techniques Criticism

The second significant criticism of the use of these tests has to do with the analytical techniques used to interpret the resulting test scores. In the same article cited above, Lucas analyzed the resultant TOUS scores from two studies; one of an Israeli population and one Australian. The reported results showed no significant differences between the two groups, yet, as a result of analysis of specific items, Lucas was able to discover that the two groups had widely divergent mean answers to a variety of specific questions.

Aikenhead (1973) poses the question "What does it mean for one group of students to have an average TOUS score 4.27 points greater than another group?" (Aikenhead, 1973, p.546). He suggests that the numerical score results of these various tests have been subjected to a variety of sophisticated statistical analyses which they neither warrant nor benefit from. He goes on to say that benefit could be derived from using the test results as the basis of a qualitative analysis rather than a quantitative one. But even this is insufficient as he fails to
take cognizance of Lucas' criticisms of the philosophical and methodological foundations of these tests, thereby leaving the implicit suggestion that the various models of science which are the basis of the tests are somehow well founded. Without appropriately and overtly acknowledging these limitations researchers are tempted to overstate their conclusions.

4.0 Conclusions

In all of the foregoing, it should be clear that the wide variety of instruments available for testing the understanding of 'the nature of science' have serious foundational flaws which render them inappropriate for the task of measuring student understanding. They each have implicit assumptions and their use as quantitative measures yields results which are insufficiently robust. As 'understanding' of the scientific enterprise is a clearly important curricular objective, and is held to be so by both practitioners and theorists, a great deal of work is required in this area of measurement.

Researchers intending to carry out work in this area need to undertake the construction of suitable tests. Such tests would be most useful if they acknowledge the criticisms outlined in this chapter. Firstly, Aikenhead's criticism of their use as quantitative measures is significant and his suggestion that there ought to be more focus on the interpretation of the data in the qualitative domain is well founded. It would seem reasonable that 'understanding the nature of science' cannot have any meaning at the quantitative level unless or until there is a universally accepted meaning or value that can be ascribed
to the concept. Secondly, given the variety of valid philosophical approaches to such meaning, any test constructed should take this variety seriously, such that the test is capable of reflecting and reporting this diversity.

In keeping with these two fundamental criticisms, it would appear that the idea of isomorphic mapping of a student's understanding of science against the criteria of various philosophers may be helpful. In this case, the test should include item stems with a variety of multiple choice responses. The marking of such a test would be geared towards determining how closely an individual student's understanding was isomorphic with a given philosophical position. Students would then be able to be instructed in such a way as to permit the development of a consistent position which would subsequently be able to be applied to various practical decisions. Students with a consistent position should be much better equipped to make the type of social and political decisions about the function and role of science in our society which they, as citizens, will be called upon to make. Furthermore, science educators will be consciously reinforcing the epistemological relationships between the sciences and ensuring a deeper and more significant understanding of the nature of science itself amongst their students.
Chapter 3

Methods

1.0 Introduction

The review of the literature substantiates the dual claim that there are a variety of natures of science and that assessment of this curricular objective should reflect this diversity. In asking the substantive and the methodological questions, this study adopted a variety of methods. Its exploratory nature meant that some methods were utilized both to generate substantive claims as well as to propose solutions to the methodological concern. In this sense, the two questions were mutually informing in the design of the study.

2.0 Design Of The Study

The study itself has three main components; one conceptual, one empirical, and the third, clinical. The conceptual component was comprised of the following steps:

1. The description of each of the guiding typologies, based primarily upon the work of Suppe and Brown.
2. Selection of items from the B.C. Science Assessment instrument which attempt to measure one or more aspects of the nature of science.
3. An informal content analysis of each item with its associated distractors to determine which implicit philosophical position could be
identified. Each item number and an associated distractor was assigned to one of the two typologies. Some distractors were seen to be consistent with two typologies, depending upon the interpretations taken by the student.

The empirical component of the study comprised the following steps:

1. A simple frequency count was made of students conforming to each of the proposed typologies.
2. A cluster analysis of the responses of a random sample of the students was undertaken to determine if there was a significant grouping of students which held a position which was not equivalent to either of the proposed response patterns.

The clinical component was comprised of the following step:

1. Interviews with a small group of typical Grade Twelve students were carried out to gather further support and illucidation of the typologies proposed. These interviews were preceded by the administration of a test composed of eleven nature of science items from the E.C. Science Assessment Instrument. The interviews were conducted to determine the meaning of each student's responses within a particular typology.

3.0 The Questions

The initial point of departure for this thesis was the
Scientific Literacy items of the 1978 B.C. Science Assessment. This goal area of the Assessment was defined by the authors as including the "understanding and appreciation of the nature of science and its methods, and the ability to interpret discussion of science-related issues" (Science Assessment Contract Team, 1979a, p. 39). Of the 20 items included in Booklets A and B of the Grade 12 instrument 11 were selected. The nine questions which were not included were reading items. For example, a passage from an article describing pulp and paper processing was followed by four questions designed to assess a student's reading and comprehension. One question dealing with stereotypes of scientists was also not included. All of those which were included were judged to be suitable and relevant for the purposes of this study.

The following items were selected: A 8, 19, 20, 21, 46, 56, and B 19, 20, 21, 28, 49. Throughout this thesis they are referenced sequentially from number 1 to 11. They are printed in full in Appendix A.

4.0 The Typologies And Response Patterns

The typologies result from an analysis of Suppe's and Brown's discussion of the distinctions between what Suppe calls the 'received view' and the 'Weltanschauungist analysis' and which Brown calls the 'Logical Empiricist' tradition and the 'New Philosophy of Science'. Brown's 'New Philosophy of Science' is basically the 'Weltanschauungist Analysis' with additional arguments based on some of the more recent realist analyses of science.
The typologies are derivative in the sense that each is a generalization of a number of highly specified positions. It is argued that these more general formulations, which tend to ignore important differences within each tradition, are at the very least an honest presentation of the very significant differences between each tradition. Furthermore, for the purposes of this study, increased precision would render the typologies useless in the analysis of high school student's understanding of the nature of science.

The two response patterns, Empiricist and Weltanschauungist, were constructed by means of an analysis of the stems and associated distractors of each item. The attempt was made to choose a separate distractor from each item for assignment to each typology. In many cases this was not possible. Each assignment was made on the basis of arguments derived from one of the two typologies. It must be explicitly stated that these patterns were generated for use as a first-order analytic tool. As will be clear in Chapter 4 there are a number of ways in which a response could be selected, each of which would be philosophically consistent within one perspective. These response patterns are only for use as a paradigmatic example of the type of analysis required.

5.0 The Interviews

5.1 The Subjects

Nine students (7 boys and 2 girls) were interviewed for this study. They were divided between humanities (4) and science (5) majors. All were in their graduating year and were either 17
or 18 years old. They were volunteers from the classes of two teachers in the same middle-class, suburban school in North Vancouver, E.C. As the school allowed student selection of both course and teacher, and they were eager volunteers (being interviewed during lunch and after class), they cannot be said to be a representative sample. They did, however, represent a range of achievement levels as reported by their teachers.

5.2 The Format Of The Interviews

Each interview was between 45 and 60 minutes in length. Immediately prior to the interview, the test based on the Science Assessment items was administered to each student. The interview was non-structured but centered on the student's responses to the items. The general protocol called for an ordered sequence of questions of the following form:

1. On this question you have selected answer X. Would you explain why you chose this answer?

2. Could you say why you rejected answer Y?

3. Could you say why you rejected answer Z?

At many points in the interview, questions were posed that called for further elaboration of points the student had raised, or followed up on tangential issues. In this sense it was non-structured. The style of interview is common in educational research. For a further discussion of its merits and method see Erickson (1975).

6.0 The Analysis Of The Data

6.1 The Science Assessment Data

The Science Assessment instrument was administered to a
total of 26,416 Grade Twelve students, representing 79% of the total enrollment for that month. A random sample of 10% provided by E.C. Research, the administrators of the data, was subjected to two analyses. The first analysis was a simple frequency count of the response profiles. The second analysis was a cluster analysis. It attempted to group students on the basis of a step-wise association by profile similarity. The existence of natural groupings within the population can be discovered on the basis of sudden jumps in the error value associated with each successive grouping step. The program is public and lodged at the Computing Centre of the University of British Columbia in the public file *CGBCUP.

6.2 The Interview Data

The interviews were analysed in three ways. The first analysis evaluated the responses in comparison with the student's distractor selection to determine whether the question had face validity for the student involved. The second analysis determined the construct validity of the typologies. The responses were analysed for evidence of reasoning which paralleled the reasoning given in the response pattern for the same question. The final analysis attempted to generate an idea inventory for each student. This was aimed at conserving the integrity of the student's position. Each transcript was analysed for ideas relating to one of four central issues in the philosophy of science. The issues were drawn from the work of Suppe and Brown. The following categories constituted the inventory:

1. Rationality in the evaluation of scientific
theories

2. Objectivity in scientific observation and method
3. Discovery in science
4. The growth of scientific knowledge

In Chapters 4 and 5 the results of these analyses are presented and elaborated upon. Problems encountered in the use of these methods of analysis are also discussed as results of the methodological question. Chapter 4 is seen as the results of the conceptual analysis and Chapter 5 the results of the empirical and clinical analyses.
Chapter 4

Philosophical Typologies

1.0 Introduction

Chapter 2 established the need for the development of an instrument which attempts to evaluate both a student's familiarity with a variety of perspectives as well as their understanding of a particular, chosen position. A necessary precondition to such work is the elaboration and description of the variety of perspectives currently held by philosophers of science. This chapter takes as its task the elaboration of broad perspectives which are both tenable and useful. Two such broad schools are identified which contain within them the wide range of perspectives currently advanced in the philosophy of science. The two positions to be considered are the Logical Empiricist and the Weltanschauung (Suppe, 1977; Brown, 1977). Amongst the Logical Empiricists are those philosophers who took up the work begun by the Vienna Circle such as Rudolf Carnap, H. Feigl, C. Hempel, E. Nagel, K. Popper, W. Quine and H. Reichenbach. Weltanschauungists include those who began the concerted attack upon Logical Empiricism in the late 1950's and those who have since evolved their criticisms into a relatively complete philosophy. Such thinkers as T. Kuhn, F. Feyerabend, R. Hanson, S. Tculmin, and H. Brown exemplify this tradition.

2.0 Logical Empiricism

As a philosophy of science, Logical Empiricism began in and
dominated the first half of this century. The following analysis is heavily borrowed from Suppe's 'The Structure of Scientific Theories' and Brown's 'Perception Theory and Commitment: The New Philosophy of Science'.

In its early years the movement sought to combine Humean classical empiricism with the symbolic logic of Whitehead and Russell's 'Principia Mathematica'. From the Humean point of view, as adapted by Logical Empiricism, knowledge consists of propositions which are meaningful only insofar as they are verified by reference to experience. Scientific propositions are analysed to be true or false by means of observation and the application of the rules of Principia Logic. Atomic propositions are true or false by observation alone. Combinations of atomic propositions (molecular propositions) are held to be true or false firstly by observing the world for the truth of the constituent atomic propositions, and secondly by applying the logical rules in the analysis of the structure of the molecular proposition. While the movement was first known as Logical Positivism, the name change arose as a result of the failure of the logic in articulating a 'verification theory of meaning'. By this it was meant that a proposition could only attain meaning through empirical verification. Since many scientific propositions are formulated as universal propositions whose atomic constituents cannot be verified by a finite number of observations, Logical Empiricism adopted a weaker position. This weaker form of the argument required only that meaningful propositions be testable in principle by reference to experiment and observation and that such observations lead to 'increasing
confirmation'. Thus the inductivist challenge to Positivism led to the development of Logical Empiricism, though the movement has been commonly referred to by both names.

Logical Empiricism holds that the function of science is to generate a system of verified, infallible propositions which explain and predict the nature of reality. Verification is taken to mean increasingly confirmed by observation. Infallibility of scientific statements is demanded by traditional epistemology and guaranteed by the appropriate application of Principia Logic to the analysis of scientific statements. Explanation and prediction are of two forms. Firstly, a satisfactory explanation consists of a deductive argument containing premises which are both true, and from which the phenomenon could have been predicted. Secondly, theories and laws of a narrow range of applicability are in themselves explained by subsumption under successively broader theories and laws. Taken together, verification, testing, infallibility and explanation result in scientific knowledge which has the epistemological consequence of being, by definition, a true and correct description of reality.

These epistemological pre-suppositions define the main problems in philosophy of science for Logical Empiricism as well as their response to challenges arising from competing positions. For Logical Empiricism, the major problems are those of confirmation, testing, theoretical terms (meaning) and explanation. Over the period of time in which Logical Empiricism was dominant, these three issues constituted the focus of the
majority of the work in the philosophy of science. Towards the end of this period, many workers within the Logical Empiricist tradition had achieved a consensus on adequate accounts of these major issues. At about the same time, however, attacks from outside the tradition began. Working from alternate assumptions, those philosophers, referred to by Suppe (1977) as the Weltanschauungen Analysts, raised a number of alternative issues to be central to the task of articulating an appropriate theory of knowledge. Logical Empiricism developed somewhat consistent responses, within their own perspective, to these new issues.

3.0 Weltanschauungen Analysis

The attack on Logical Empiricism in the late 1950's began at the epistemological centre. On any account of Logical Empiricism, empirical data are taken to be independent of any theory used in their interpretation, and are, therefore, the basis of reference for the meaning and truth of any scientific proposition. The central core of the emerging analysis was a criticism of Logical Empiricism's theory of perception. While Logical Empiricism held that any two observers viewing the same phenomenon will have the same perception, the Weltanschauungists held that the act of perceiving was heavily influenced and affected by the nature of the theories and assumptions held by the observer. Furthermore, two observers from differing theoretical perspectives, it was argued, would have quite different experiences. This claim, viz. the theory-ladeness of data, became one of the central issues of the emerging analysis.

The Weltanschauungist commitment to the doctrine of the
theory-ladeness of data allowed for the resolution of a long standing debate within Logical Empiricism. At issue was the significance of the history of science for the philosophy of science. Logical Empiricism had long argued for the normative, rather than the descriptive function of philosophy. The incongruities between Logical Empiricism's view of science and the developing understanding of the history of science stimulated the Weltanschauungists to adopt the history of science as the starting point for their philosophy of science. Armed with a new theory of perception, and using the history of science. As the basis of their philosophy of science, the Weltanschauungists began the process of working out the details of a new epistemology. In addition to the older notion of absolute truth, called by Brown, Truth\(^1\), i.e. a correct description of reality, the Weltanschauungists developed a doctrine which held that there was a second type of truth, Truth\(^2\), which was that which was taken to be true. In so doing, the traditional relationship between knowledge and truth was inverted. Where previously if something was known it could only be, by definition, True\(^1\), under the new conception something known is only True\(^2\), and not necessarily True\(^1\). Scientific knowledge ceases to be the body of verified, infallible propositions, and becomes instead the body of statements which scientists take to be true. Such a relativistic picture, it is argued, more accurately reflects the nature of science as practiced, both currently and historically.

4.0 Issues In Philosophy Of Science

For the past two decades, Logical Empiricism and
Weltanschauungen Analysis have centred their debate on the common issues for any philosophy of science. The issues, notably 1) the role of rationality in evaluation of scientific theory, 2) objectivity, 3) the place of scientific discovery in philosophy of science and 4) the nature of the growth of scientific knowledge; have been approached from the presuppositions of each position. One may conceive of these issues as being the tip of an iceberg; the tip being supported by a deep philosophical debate with respect to its epistemic and metaphysical foundations. It is the tip, however, which has the most visibility. These surface expressions of the philosophical debate constitute, for the most part, the philosophy of science as taught and discussed in our schools. As noted in the review of the literature, it is hypothesized that students may hold a variety of positions on these issues, and evaluation of this curricular objective should, therefore, allow for achieving an understanding of both a student's consistency within one perspective as well as his/her knowledge of others. What follows is the explication of each issue from the two perspectives. As such, they form the basis of the typologies used in the analysis of the data.

4.1 Rationality

Within the practice of science, rationality has occupied a central position. In the generation of hypotheses and theories as well as the evaluation of subsequent knowledge claims, rationality has provided the criterion of judgement. Given the assumptions of Logical Empiricism, with its basis in Principia Logic, rationality was clearly defined as the application of an
appropriate algorithm. It sought a logical algorithm which could guarantee the infallibility of its results in the same manner in which arithmetic algorithms guaranteed their results. As Brown points out:

...the project is to find an algorithm on the basis of which we can evaluate scientific theories, the assumption being that even if we cannot prove the final truth of an hypothesis, we can produce a set of rules which will allow us to determine the degree to which it has been confirmed by the available evidence. (Brown, 1977, p. 146)

The definition of rationality as algorithmic, while demanded by an epistemological commitment to the doctrine of absolute and infallible knowledge, is clearly an attempt to eliminate human judgement, by definition fallible, from the scientific enterprise. The consequence of such a position is belief in a single scientific method, which, if followed, guarantees knowledge. Such a conception is often presented, at least implicitly, in school curricula.

On the Weltanschauungist view, rationality is demanded in precisely those cases in which an algorithm cannot be applied, and therefore, rationality is, in fact, informed and reasonable human judgement. In a situation in which the observation produces results inconsistent with those deduced from the theory, a judgement is called for in order to determine whether the evidence represents a counter-instance and therefore a refutation of the theory, or whether it represents a research
problem. In developing this underlying conception of rationality, Brown proposes the adoption of Aristotle's concept of the man of practical wisdom from the Nichomachaen Ethics as the basis for a model of rationality. In this way, rationality is freed from the need to produce infallible results and therefore more closely concurs with the relativistic epistemology of the Weltanschauungist position. Under Logical Empiricism, the application of the algorithm was taken to generate knowledge. For the Weltanschauungist, rationality is exercised by individual scientists and knowledge is arrived at through the consensus of the relevant community. As Brown points out:

A central characteristic of our new model of rationality is that it recognizes that different thinkers can analyse the same problem situation and come to contrary conclusions without any of them being irrational. But the fact that a theory is arrived at rationally is not sufficient to make it part of the body of science; that requires not an individual but a group decision. (Brown, 1977, p. 150)

The epistemological problem then becomes to understand how consensus is achieved.

4.2 Objectivity

Objectivity is guaranteed, within Logical Empiricism by strict adherence to the primacy of empirical test. Any hypothesis is accepted on the basis of the empirical data, and may subsequently be increasingly confirmed by intersubjective
testing to eliminate the potential of human error.

On the Weltanschauungist view, a variety of positions exist. Kuhn and Feyerabend clearly argue for a subjective, sociological view of science and its knowledge. Others such as Erown, accept many of the Weltanschauungist presuppositions yet conclude that science is, or can be, objective.

Barber (1974) argues that there are three Weltanschauungist theses which usually result in the conclusion that science is subjective. These are 1) the theory-ladeness of data, 2) the resistance of comprehensive theories to falsification, and 3) the absence of a criteria for choice during periods of 'revolutionary' science. He argues in favour of three additional theses which serve to preserve some semblance of the objectivity of science. Firstly, although all data are theory-laden, between competing theories there is a common core of observations about which both sides may agree. Secondly, though comprehensive theories are highly resistant to falsification, they are ultimately subject to the dictates of anomalous observations. Thirdly, though there is no internal set of criteria for choice between competing paradigms, valid criteria are called upon from closely related fields with which the scientist must maintain some coherence. He concludes that the result of these three appended theses, if not a guarantee of classical objectivity, at least moves science from the totally subjective positions of Feyerabend and Kuhn.

4.3 Scientific Discovery

Scientific discovery was, for the majority of the Logical
Empiricists simply a non-issue. By distinguishing between a context of discovery and a context of justification (acceptance of a theory), and further assuming that discovery occurs ex nihilo. Logical Empiricists successfully argued that only justification was a logical operation and hence subject to philosophical analysis.

The Weltanschauungists, however, countered with a variety of positions. Hanson contended that the failure of deductive logic to provide a logic of discovery could be met with a different type of logic. Applying retroductive reasoning to the problem, he said, would render discovery philosophically analysable (Suppe, 1977, p.357). This approach, drawn from C.S. Pierce's idea of the resolution of an enthymeme (the discovery of a missing premise), while not so much a new logic, has at least been suggestive of possible directions for study. Brown has continued in a similar line by suggesting that the problem might be handled by an erotetic logic. He argued effectively that discovery is not a single, isolated event, but rather that it occurs in relationship to the background of scientific knowledge and problems. Therefore, a logic of relationships, as opposed to a logic of forms (viz., deductive logic, a purely formal system) is required for its analysis. He argues:

Efforts to construct a formal logic of discovery are highly implausible ... Exactly because it is impossible to understand the structure of scientific reasoning without understanding its content in its historical setting. What the
concept of dialectical logic provides, then, is a tool for examining the structure of research in terms of the historical context. (Brown, 1977, p. 134)

Discovery is a significant issue for the Weltanschauungist position because they view science as a social activity. As such, an understanding of it is critically dependent upon seeing science developmentally. The development of theories from their genesis to their overthrow is both a product of and a contributor to the context in which science is carried out. Since the problem of discovery is not yet resolved, the principle of its importance as a question worth asking must continue to be stressed.

4.4 The Growth Of Scientific Knowledge

One final problem of the philosophy of science is the need for a satisfactory philosophical account of scientific progress in the growth of knowledge. The Logical Empiricist position on this matter was dependent on the concept of theory reduction. On this view, progress in science occurs in three ways; 1) through a theory's loss of confirmation (predictive accuracy) as a consequence of technological improvement in measurement, 2) by expansion or extension of a theory's scope of application, or 3) the reduction of one or more highly confirmed theories of limited scope to a single, more comprehensive one. As Suppe summarizes:

The thesis of theory reduction thus results in
the following picture of scientific progress or development: science establishes theories which, if highly confirmed, are accepted and continue to be accepted relatively free from the danger of subsequent disconfirmation. The development of science consists in the extension of such theories to wider scopes (the first form of theory reduction), the development of new, highly confirmed theories for related domains, and the incorporation of confirmed theories into more comprehensive theories (the second form of theory reduction). Science thus is a cumulative enterprise, extending and augmenting old successes with new successes; old theories are not rejected or abandoned once they have been accepted; they are just superseded by more comprehensive theories to which they are reduced. (Suppe, 1977, p.56)

Central to this notion is the doctrine that the constituent terms of the theory do not change their meaning during the course of reduction.

For the Weltanschauungists, beginning as they do with the data of the history of science, the concept of the unchanging nature of scientific terms over time was unacceptable. Consequently, in what is probably the most popular of the attacks on this thesis, Kuhn's 'Structure Of Scientific Revolutions' advanced the theory that growth in science is achieved as a consequence of a gestalt shift in the perception
of a scientist, such that data are seen in a new way leading to alternate theoretical explanations. Gradually, the alternative theory gains adherents which begin to constitute the core of the scientific community, which leads to the revolutionary overthrow of the previous theory and the new theory taking its place as the paradigm of the science. In the process, the two sides of the revolutionary debate cease to be speaking the same language. Terms in one theory do not entail the same understanding in the other.

Alternative accounts within the Weltanschauung tradition have been offered by other philosophers. Feyerabend has developed a theory in which discrepancy between data and theory is eliminated by either a) discarding the theory, or b) discarding the observation. Going further, he suggests:

...introducing, elaborating, and propagating hypotheses which are inconsistent either with well established theories or with well established facts. Or, as I shall express myself, I suggest proceeding counter-inductively in addition to proceeding inductively.

(Suppe, 1977, p. 642)

Such a counter-inductive proliferation of theories, exemplifying Hegel's dialectic according to Feyerabend, will ultimately lead science to the truth about the nature of the world. Such epistemological anarchy has not been taken up by other scholars.

Taking a more moderate position, Brown argues in favour of the thesis of dialectical theory succession. As has been noted
above, he has taken a non-Hegelian, Platonic sense of the term and suggests that:

A dialectical change from one theory to another is a reorganization of the strands of the theoretical web, along with the removal of some strands and the addition of others; this reorganization accounts for the changes in meaning of scientific concepts associated with a scientific revolution, since both the concepts and the data of the theory derive their meaning from their location in the theoretical web. But theory change takes place within definite problem situations, within which the strands retained in the new theory provide the continuity of development and the grounds for comparison even though these strands take on a different meaning in the new theoretical structure. (Brown, 1977, p. 140)

Such a position wedds many of the dominant themes from other Weltanschauungist positions and serves as a good summary of this view of the growth of knowledge.

5.0 The Response Patterns

The preceding sections established two typologies in the philosophy of science. These generalized presentations will now be used in the development of two patterns of response to questions on the nature of science. Again the reader is reminded that these patterns have been primarily developed as an example of an analytic tool. They represent one philosophically
defensible pattern but are presented in the full knowledge that alternative formulations are equally justifiable. These patterns of response constitute alternatives which could have been chosen by students who took the 1978 Provincial Science Assessment exam. It is suggested that a student who held a consistent Logical Empiricist or Weltanschauungist understanding of the nature of science would have chosen the appropriate pattern of responses.

Due to the nature of the questions, there are several responses which are representative of both, but for significantly different reasons. Clinical interviews were conducted in order to determine the student's reasoning behind particular response choices.

5.1 The Questions And Their Responses

1. About what topic do scientists know everything?
   A) clouds.
   B) stars.
   C) trees.
   D) no topic.

The response in both patterns should of course, be (D). From the Logical Empiricist position, it is in principle, possible to know everything about a topic. At the present time, however, no topic is completely known. For the Weltanschauungist, the answer will forever remain (D). One consequence of shifts in perception is that at any time in the future new ways of looking at the data re-define what is known.
2. Astrologers use the position of the stars and planets at the hour, day, and minute of a person's birth to predict his future. Which one of the following statements regarding this practice would be accepted by scientists?

A) The modern astrologer can now predict one's future more accurately because better telescopes are in use.
B) There is no evidence that astrologers can predict the future of an individual on the basis of stars and planets.
C) Some astrologers inherit the ability to understand the stars from their mothers or their fathers.
D) Study and long years of training in astrology make an astrologer's predictions of one's future more accurate.

Again both positions should choose (B). This item attempts to solicit answers to a question about what constitutes a science, and how it is conducted. Both positions concur that at a fundamental level, to 'do science' means to have an explanatory theory about something which is subject to validity checks through reference to the world. It is a question of what is an adequate criteria for evidence.

3. Which of the following statements best describes the connection between science and technology?

A) Technology involves the practical
applications of scientific knowledge.
B) Science depends on technology for ideas and the organization of experimental work.
C) Workers in science use the laws and principles discovered by workers in technology.
D) Technology is the part of science that deals with mechanical problems.

Once more, both positions concur on (A). As with the previous item, what is at issue is essentially a matter of mutually agreed upon definitions. It does not touch upon issues of joint concern.

4. Are biology, chemistry and physics related?
They are:
A) not related because they are built on different sets of fundamental principles.
B) related because observations, principles, and ideas of each field have connections with the other two.
C) related because mathematics serves to unify the sciences.
D) not related because biologists, chemists, and physicists study very different natural phenomena.

Here differences begin to emerge. (B) is the choice consistent with a Logical Empiricist position. It is Logical Empiricism's thesis that the sciences are related, particularly
at the level of observations, as a consequence of their theory of sense-data perception. The sciences are further related through theory reduction which presupposes unity of meaning of theoretical terms between the sciences. The Weltanschauungist position, however, would support the choice of (A) and its related choice, (D). Not only are the different sciences based upon differing underlying assumptions but furthermore, the same science can have, during periods of revolution, differing fundamental assumptions.

5. A student wrote the following note on a laboratory project: 'Using a cork-borer I obtained several cylinders from a large potato. The cylinders were 7 cm long and .5 cm in diameter. I kept them on a dry plate and measured them again on the following day. I found that all of them had become shorter and thinner.' The student then put the cylinders into a beaker of tap water and wrote: 'If I measure them tomorrow I shall find that they have all returned to their original size.' In writing this last sentence, the student was:
A) making a statement of fact.
B) drawing an observation.
B) drawing a tentative conclusion.
D) describing an experimental procedure.
E) making a hypothesis.

The choice of both positions would be (E), but with
differing implicit understanding of the course of action to follow should a discrepancy arise between prediction and observation. For the Logical Empiricist such a discrepancy must result in the rejection of the hypothesis. For the Weltanschauungist observation depends so heavily on the theory held that, depending on the theory, either the observation becomes a research problem or the observation may not be the same as that of the Logical Empiricist and hence not be problematic.

6. In discussing the problem of nuclear proliferation, a famous scientist declared that Canada must provide more Candu reactors for developing countries. What is the best evaluation we can give to this scientist's statement?
A) His conclusion is probably right, since he approaches the problem with a scientific attitude.
B) His conclusion is probably wrong, because scientists seem to be trying to destroy the world.
C) His conclusion and reasons are probably correct, because scientific results are the most reliable kind.
D) His conclusion and reasons should be weighed according to his knowledge of international affairs.
Both positions would support the choice of (D). Empiricist and Weltanschaungist leanings may be uncovered in the interview situation. In discussing the distractors some students could claim that a scientific attitude will more likely lead to a more correct conclusion. This could result from applying the Empiricist claims about the scientific method to any results of investigations carried out with a scientific attitude. On the other hand, some students could also discuss the impact of social and political assumptions on the public pronouncements of scientists. While the question, as it is constructed, allows for no discrimination between students on the basis of their distractor choice, the item is a rich stimulus for the interview.

7. It has often been said that published reports of scientific research are generally very accurate and honest.

A) This is true because scientists are very accurate and honest people.

B) This is true because only one answer can be correct in science.

C) This is true because reported results can be checked by other scientists.

D) There is little basis for this claim.

For Logical Empiricists the answer is (B) as a consequence of their doctrine of the theory-independence of data. Research reports are accurate and honest because there can be no disagreement on observation statements. On the other hand (C) is
also plausible according to the notion of increasing confirmation. The tenor of statement (C) however is more closely related to a notion of intersubjective testing's cruciality and on this account could be taken as supportive of Brown's Weltanschauungist position. A final wrinkle can be added by pointing to the plausible addition of (D) as supporting a more Kuhnian Weltanschauungist position on the argument that scientific reports are simply the result of being trained to see things from a particular perspective.

6. An example of a scientific model is: 'The atom is like a miniature solar system composed of electrons in orbits, and in the centre, a nucleus containing protons and neutrons.' Which one of the following statements about scientific models is not correct?
A) They are man-made constructs and may not represent reality.
B) They consist of a relatively small number of assumptions.
C) They represent what scientists could see with very powerful instruments.
D) They are tentative and may be modified or discarded.

Firstly it must be pointed out that this question has been formulated in such a way as to discourage students from selecting distractors which they may find appealing. By requiring that students choose the distractor which is not
correct, valuable insight into their understanding is lost. For example, an argument can be made for the position that (A) represents the choice of the Logical Empiricist position. Taking the notion of Truth\textsuperscript{1} the claim could be made that a Logical Empiricist should conceive a model as being quite clearly representative of reality. This position is in agreement with Suppe's discussion of iconic models, i.e. those which are structurally similar (isomorphic) to what they model (Suppe, 1977, p. 57). On this view the Logical Empiricist choice of (A) can make sense. Unfortunately, due to the nature of the question, the choice of (A) entails the acceptance of all other distractors as being true, which may not be the case. The Weltanschauungist position would claim (C) as being correct.

9. A coal-burning electric plant is proposed in your area. The power plant will reduce the cost of electricity as well and prevent future power failures. It will also discharge heat into the environment and cause some air pollution. What should be done?

A) Build it. You can save money.
B) Build it. It will be good for the community.
C) Build it. You will have all the electricity that you need.
D) Don't build it since it will pollute the water and air.
E) Don't build it without first determining the effect on the environment.
Selection (E) is appropriate to both perspectives, however, further questioning should be able to uncover differing supporting reasons. A Logical Empiricist should argue that science, given time, might determine these effects while the Weltanschauungist would recognize that various political perspectives held by the scientists will effect their evaluation of the evidence.

10. Which of the following is the most urgent problem with regard to recombinant DNA research?  
A) Ensuring that controls are effective and enforced.  
B) Keeping scientists from fooling with nature in this way.  
C) Keeping government from interfering with scientific research.  
D) Making sure scientists don't create monsters in their laboratories.

A Logical Empiricist response would be (C) on the argument that science gua research method must remain independent from outside influences if it is to be able to guarantee the truth of its results. The Weltanschauungist response would be (A) on the argument that values are inherent in the practice of science and as a consequence, on issues of such general importance, outside influences and controls should be explicit and overtly agreed upon a priori.

11. When many new facts are discovered which do not fit a scientific theory, scientists will
usually ask themselves:
A) Shall we throw cut the theory since the facts do not fit?
B) Can we change the facts a little so that they fit the theory?
C) Shall we keep the theory as it is, since the new facts don't help it?
D) Can we change the theory a little so that these new facts will fit in?

The hard Logical Empiricist's commitment to the falsification doctrine demands the selection of response (A). A problem exists with this analysis in that at another level it could be argued that position (D) may be interpreted along similar lines. I shall return to this point in the next chapter.

Under Weltanschauungen analysis, the disagreement between observation and theory can lead in one of two directions. Firstly, the disagreement can be interpreted as a research problem for which an evolutionary revision of the theory is required. In this case, the choice of (D) is the appropriate response. Secondly, the disagreement may be considered of such magnitude that a paradigmatic crisis is precipitated, thereby leading to the selection of (A).

In summary then, the preceding response patterns are taken as representative of the two positions. Because these questions were not designed with this type of analysis in mind, problems have arisen in generating absolutely clear and dichotomized response patterns. Nonetheless, the general methodological point
has been demonstrated. A set of multiple choice questions can, I believe, be so constructed as to result in a test which may be differentially scored so as to yield results which indicate the typological orientation of the respondents. Chapter 5 will provide the results of the analysis of the empirical and clinical data and shed more light on the nature of student understanding of science.
Chapter 5

Empirical And Clinical Results

1.0 Empirical Results

This section will present the results of the two analyses of the empirical data. The first analysis consisted in a simple frequency count of a 10% random sample of those students in the B.C. Science Assessment who chose either of the pure response patterns. In this sample 6.35% had response profiles equivalent to the Empiricist profile, and 1.08% had a Weltanschauungist profile. When the profile code was widened to include those instances in which it was argued that two differing responses were possible (e.g., questions 7 or 11), the percentages rose to 10.7% and 15.6% respectively. This however, is largely an artifact resulting from the fact that in these cases there ceases to be a distinction, such that the same student is counted within both profiles. Understanding that these questions were not intended to be subjected to this type of analysis we may conclude firstly that this procedure may be enlightening in the analysis of a future set of questions which have been so designed, and secondly that ambiguities within the proposed response patterns may be resolved through interviews with the students.

The second analysis attempted to determine if there were significant groups of students who had selected a pattern of responses which paralleled neither of the response patterns
described in Chapter 4. A cluster analysis was performed using the computer programme *CGROUP* (Patterson and Whitaker, 1978). The programme successively groups students through step-wise association of students with similar profiles. The more dissimilar the response pattern being associated the higher the associated error value. Natural groupings are discovered to be those which exist immediately prior to a step in which a sudden jump in the error value occurs. This analysis was undertaken as an exploratory manoeuvre. The results were judged to indicate that no significant groups existed within the sample. Again, the ambiguous nature of the original questions precludes the use of this analysis in a conclusive manner and it is only suggested that this tool may be revealing in the analysis of a subsequent instrument.

Both of the empirical analyses were exploratory in nature. They have demonstrated the need for an instrument which has been designed to be analyzed from the profile perspective. They have also demonstrated the need for interviews with the students to begin to discover what meaning the questions and their answers had for them. The subsequent sections of this chapter report the results of the analysis of the clinical component of this study.

2.0 Clinical Results

This section will present the results of the analysis of the interview data. Three kinds of analysis were carried out, namely: 1) face validity, 2) construct validity, and 3) an idea inventory. The first analysis, for face validity, determined whether the student's response was reasoned and based on a clear
understanding of the question asked. The second analysis, of the construct validity of the typologies established in Chapter 4, determined whether the reasons offered by the student for a given distractor choice were congruent with the reasons given for either the Empiricist or the Weltanshcauungist typology. The third analysis resulted in the generation of an idea inventory for each student. The inventory was built around the four central issues in the philosophy of science discussed in Chapter 4; specifically, rationality, objectivity, discovery, and the growth of scientific knowledge.

2.1 Face Validity

Face validity was evaluated dichotomously; either a student understood both the stem and each distractor well enough to give a reason for their selection, or they did not. Such face validity was found lacking in 11 of the 97 cases. (see Table 5.1) In two of the 11 cases, the student was able to demonstrate during the interview that the lack of understanding was due to the form of the question. These two cases are indicated by the number 3 in the table. Both made an error which they spontaneously pointed out, corrected, and then provided a reason for their corrected distractor choice. It is argued that for the remaining 9, failure to understand the question invalidates the use of their response in any further analysis. In all other cases, the ability to offer a clear reason was taken as evidence of an understanding of their selection and hence was taken to be an acceptable indicator of their having made a reasoned choice.
Table 5.1

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1=understood question and offered reason
2=did not understand the question
3=corrected error during the interview
0=did not answer

As Table 5.1 indicates, the students were able to understand almost all the questions. Face validity for questions 1-4, 6, and 9-12 can be accepted in that in virtually all cases the students understood the question well enough to provide a reasoned choice. The following portion of Mark's transcript indicates the type of data used in order to judge a student's understanding of a question. The quotation is taken from a response to Question 6 which asks how we are to evaluate the statements of a scientist about the provision of Candu reactors to developing countries.

S: The approach - the scientific approach is not always correct and it maybe the clinical and the way that it should happen in a laboratory but outside it may not happen that way. In the 'real world' it may not in fact have the reaction that you got in the laboratory. So it's not always right. Scientific approach is not always right.
in the 'real world'.

I: Could you explain that one a bit more? Why is it that scientific...

S: You can't say that his conclusion is right just because he's a scientist. Because he's a scientist he may approach things in a scientific - with a scientific approach - a manner which he carries in the lab but the lab manner may not really apply in the 'real world'.

I: How could it not apply in the real world? What would prevent it from applying in the real world?

S: Other influencing factors like - in the lab it's - you don't have the influence of other people what other people are thinking. It's just an objective look at what happens - it's an idea of what happens. But on the outside there's other influencing factors like other people and a thing like Candu reactors, other people may not want it to happen or other people may have reasons that he hasn't thought of for this not happening. For instance, he says that - in here it says that he should but his conclusion may not be right because well we gave the Candu reactor to India and it became a member of the nuclear bomb club - very elite. So just because you approach it with a scientific manner it may not be right because there may be further
implications outside the scientific approach.

I: So the scientific approach then can't be applied to all problems - is this what you're saying?

S: I don't think so. Because there are abstract ideas that may influence it that can't be taken into account with a scientific approach. That may be a contradiction.

I: No that's okay. Let's move on to B then.

S: Okay, I don't know that there's any proof that scientists are trying to destroy the world so I can't say that his conclusion is definitely wrong just because of prejudice - my prejudice that scientists are trying to destroy the world.

I: Do you hold that prejudice?

S: No. I'm just saying in the sense that trying to refute it...

I: And C?

S: Science again relates to A: 'scientific results may be reliable', but they may not necessarily be the most reliable for a given situation. I don't know that I can think of an example. I'm trying to think of something that could approach it in two different manners. His reasons are - I don't know - it was just a feeling I had that the scientific results aren't always the most reliable. Okay, if the scientist hasn't brought some of his own feelings into the
conclusion then his ideas may not necessarily be reliable because he's allowed his prejudice to be part of the conclusion.

I: Do you think that happens very often?
S: I don't know whether it happens very often.

It shouldn't but it may so...

Mark has demonstrated that each of the distractors was clearly understood. In one case he was able to indicate the similarity of two of the distractors (S: Science again relates to A...) and then carried on to indicate how they were different.

Evidence for the lack of face validity was often very blunt. During the interview the student stated clearly that a term or phrase in either the stem of one of the distractors was not understood. The following portion of Lynn's transcript indicates this case:

I: In question five you selected answer E (making a hypothesis) and what I would like you to do is to explain why you didn't select answer C.

S: One reason was because I didn't exactly know what tentative means. What does it mean?

In this situation, Lynn's choice of response E does not indicate a reasoned choice but rather his lack of understanding of at least a part of one of the distractors. The following portion of Sam's transcript indicated an identical point:

I: In question 7 you didn't choose an answer, or rather you selected E (I don't know). Can you tell me why?
S: 'Cause I don't know much about scientific reports, published reports. I haven't really...
I: Have you ever come across one? Have you ever read a scientific journal?
S: No.

Sam is unable to make a reasoned choice because of a lack of knowledge about the subject of the question. For Sam, this question has no face validity. Further in Sam's transcript we found another kind of problem for face validity. In this case, the format of the question itself was the cause of the problem. In Question 8 the student was asked to select the distractor which was not a correct description of scientific models. As the following transcript demonstrates, Sam was quite capable of understanding each of the distractors and the subject of the stem but failed to note the format of what he was being asked to select.

I: On Question 8 you selected answer A. Now what I'd like you to do is to re-read the question, re-read all of the answer possibilities and explain to me how you came to choose A.
S: I'll tell you right now that this question I left out at the first time and went back to it because I wasn't sure.
I: It's a tough question.
S: Yeah. (re-reads question) Okay, you're saying that this statement is a scientific model is not correct. I feel that they can be tentative and modified and discarded so I took that one. And I
wasn't sure - like I didn't - a model I look on as not an actual visual picture but an idea rather than something, like if you magnified something that's what you'd see. I look at it as an idea rather than an actual structure. So I didn't think it would be number C.

Sam has missed that portion of the question which asks for the selection of a distractor which is not true about scientific models. The answer he actually wrote on his paper was A. The first selection he defends (I feel that they can be tentative and modified and discarded so I took that one) is distractor D. In the next sentence he offers reasons which can clearly be judged to support the choice of C; yet it is also clear that it is because he is mistaken about the format of the question that he rejects this answer (So I didn't think it would be number C).

Sam demonstrated a clear understanding of models during the interview but the problem of format inherent in the question prevented an adequate demonstration of his understanding on the test. The problem initially is that of face validity for Sam.

2.0 Construct Validity

In this analysis of the interview data the main emphasis was on the level of agreement existing between the reasons given by the student for his or her choice and the reasons given in Chapter 4 for each typology. The classification of their position based on the interview was then compared with the classification based on the answer they selected on the test. Weak agreement with a typological position consisted in the enunciation of at least one of the reasons or ideas expressed in
the preceding chapter. In some cases, weak agreement was scored even though the student made some claims which were judged as being based in the alternative typology. It was a global judgment based on the entire set of statements related to any given question which determined the classification made. In cases where the student gave a statement judged to be equivalent to the 'core' of the position as well as some further elaboration, the median score was given. Strong agreement consisted in the statement of a core position, plus an elaboration which exhibited a high degree of understanding and/or commitment on the part of the student. Examples of each type of scoring follow. A summary of this analysis is given in Table 5.2.

2.2.1 A Weak Position

On question 10, Lynn was scored as having weak agreement with the Empiricist position. The question asks what the most urgent problem is with respect to recombinant DNA research. I argued in the previous chapter that the 'core' of the Empiricist position would entail the protection of science qua research method from external influences.

S: ...I'm sure that many scientists feel like they should be allowed to do these kind of things.
I: How do you feel about that?
S: I think that they should be allowed to, to do that, of course with controls, and very tight places so that they don't make some kind of deadly virus...
While Lynn chose B (keeping scientists from fooling around with nature in this way) be ascribed that belief to 'the people'. When asked directly (quoted below) he advocated a version of the core of the Empiricist position but did not elaborate except in the direction of a weakly stated Weltanschauungist position, i.e., that society should be able to exercise some control over the activities of science.

S: Yeah, okay, that's, I took as being... That's the problem, that people don't like the scientists to fool around with nature. I'm not sure that they have a valid reason for feeling that way.

These positions result in the assignment of a weak Empiricist classification.

2.2.2 A Median Position

On the same question (Question 10), Mark was scored as being in the median of the Weltanschauungist position. The core of the position on this issue is that science is not capable of making effective decisions on such social issues without the input, guidance, and direction of the community at large. Mark's position clearly states this core:

S: You can't have people going just going around or examining or playing with it helter skelter all over the place because you could end up with...

And: S: I came down to making sure that scientists don't create a monster in the laboratory and...ensuring the controls are effective and
In these passages Mark has stated the basic position. In the following passage he elaborates the reasons for his choice of B (making sure scientists don't create monsters) rather than A (ensuring that controls are effective and enforced).

S: It seems to me that every time that rules are put in somebody breaks them. So you put down the rules and somebody breaks them and they make a monster then you're in trouble. If you - you can't inspect everywhere because there's going to be places that don't know about or that the government doesn't know about.

Mark appears to be saying that his choice of B was based on his sense that A didn't represent a strong enough statement. The phrase "controls are effective and enforced" appears to suggest to Mark a weaker position than "making sure scientists don't...". This kind of elaboration of the core position was judged to represent the median Weltanschauungist position and Mark was classified accordingly.

2.2.3 A Strong Position

Question 11 deals with the relationship between theory and observation. It asks for the selection of a course of action to follow when a theory is confronted with a recalcitrant observation. On this question Sam was scored as holding a strong Weltanschauungist position.

The argument in Chapter 4 identified distractor D (change the theory a little so that these new facts fit in) as the
Weltanschauungist position. The position taken there was that for the Weltanschauungist, disagreement between theory and observation is resolved through the evolutionary revision of the theory. This position applies during periods of Kuhnian 'normal science'. Distractor A (throw out the theory) was argued as being the Empiricist position based upon their doctrine of falsificationism. Going further, it can be argued that the Empiricist position is similar to the Weltanschauungist position during periods of Kuhnian 'revolutionary science'.

Sam chose distractor D, and hence could be classified as a Weltanschauungist. In his very first statement, however, he demonstrated a much more sophisticated understanding by alluding to the distinctions to be drawn between revolutionary and normal science.

S: Well, it's just - on this it depends on how many, like what kind of new facts are brought out, as to whether A should be chosen, 'should we throw out the theory'.

He indicates that there is both a qualitative and a quantitative dimension to the recalcitrant data. Both considerations need to be taken into account when choosing between distractors A and D.

Sam continues:

I: Okay, how can we tell when we should do which? (A or D)
S: Well I think it depends on the strength of the facts.
I: Do facts come in varying strengths?
S: Yes. Well it's the conditions under which the
facts were taken and maybe a new aspect is brought in which the theory doesn't accommodate and then the theory can be altered and it will accommodate that and the rest of it may hold true.

Again he points to the variable impact of facts. In choosing the word 'aspect' Sam seems to be struggling with Kuhn's notion of perceptual or gestalt shifts.

I: Would it be possible for two different scientists to observe the same thing and report different facts?
S: Under different conditions it might be.
I: How about under the same conditions?
S: Probably not. Well it could depend on the interpretation too.
I: How does interpretation fit in?
S: Well because if you look at something you can interpret actions of the thing or whatever different than somebody else.

In pushing this idea further, Sam was able to articulate a very sociological view of how difference in perception can arise.

I: Where do these viewpoints come from?
S: It's just the ideas you're brought up with.
I: The way you were brought up would affect how you see things?
S: Well like if you were in something or something like this and then a new idea is brought in it may depend on how you were brought
in to or something like that. I can't.. Like if you were taught a concept and you took the concept a certain way and somebody else took that concept another way they may conflict at some time.

Sam has not only grasped the core of the Weltanschauungist position but he has demonstrated both a sophisticated understanding and a commitment to it. For these reasons, Sam's transcript was judged to be exemplary of a strong position.

2.2.4 Validation Of The Typology Construct

Earlier in this chapter it was stated that congruence between the reasons offered by the students for their choice of distractor and the reasons given a priori in Chapter 4 for the typologies would be taken as a measure of the construct validity of the the typologies. The typologies presented were developed prior to the interview phase and are therefore quite independent of the student responses. Table 5.2 reports the typological classification of the students' distractor choice in column one and the classification of their interview response in column two in each case.

It was argued in the previous chapter that the same distractor was representative of both typologies in Questions 1,2,3,5,6,8, and 9. It was further argued that questioning during the interview phase should provide insight into the beliefs and ideas of students holding differing viewpoints. In examining Table 5.2 it is clear that on Questions 1,5,6,8, and 9, students with divergent perspectives did indeed choose the same
Table 5.2
A Summary Of Student Answers And Typological Classification

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1. The First Column For Each Student Represents The Classification Of Their Distractor Choice.
2. The Second Column Represents The Classification Of Their Interview Response.
W=Weltanschauungist   E=Empiricist   B=Classified As Both 0=Other Or Unanalyzable

distractor and for differing reasons. Of the 45 responses to these questions, 15 were unanalyzable. Either the student made insufficient comment to allow the author to make a defensible judgment or said nothing at all. Of the 30 responses which chose a distractor which had been classified as representative of both typologies, 16 were classified as responding from the Weltanschauungist perspective and 14 from the Empiricist perspective. On Questions 2 and 3, with 18 possible responses, 11 selected the distractor identified in the typologies. None of their responses, however, were analyzable. This too, was suggested in Chapter 4. In effect, Questions 2 and 3 call for definitions which both 'views' of science agree upon. Worded
differently it would be possible to provide some interesting avenues of discussion but in their present format the responses were not fully useful. The discovery that students choosing the same distractor did so for differing reasons and that their differing reasons paralleled the reasoning given in the response profiles in Chapter 4 is taken as moderate support for the construct validity of the typologies.

On Questions 4, 7, 10, and 11 both an Empiricist and a Weltanschauungist distractor was identified. Of the 36 responses, 10 chose distractors other than those classified as representative of one of the typologies. In 21 of the remaining 26 responses (80.7%), the interview response classification matches that of their choice of distractor. It would appear that there is supporting evidence for the claim that the typologies presented have a reasonable degree of construct validity and may be of use in the measurement of student understanding of the nature of science in a questionnaire format. Such questioning adds both a depth and a breadth which is left uncovered when utilizing the standard instruments and analysis. Further depth may be achieved through an analysis resulting in the generation of an idea inventory. Such an analysis is discussed in the next section.

2.3 An Idea Inventory

The interviews conducted with these students took as their starting point the items from the Science Assessment. These items, however, were intended to be a stimulus for discussion about each student's ideas on the nature of science in a broad
sense. This rich source of data has been analysed in such a way as to generate an inventory of each student's ideas. The inventory itself was organized around the four central issues in philosophy of science identified in Chapter 4, namely: 1) rationality, 2) objectivity, 3) discovery, and 4) the growth of knowledge.

While the previous analyses resulted in identifying student's ideas on specific questions with those of either of the typologies, the present analysis can be used to generate a kind of second order understanding of a student's complete set of ideas which conserves the integrity of each student's entire position. At the same time, this inventory can be utilized as a measure of consistency within a student's own perspective and point out the areas and directions in which future study should proceed.

2.3.1 Mark's Inventory

Mark's interview (Appendix B) was selected as the basis for a sample inventory. The items in the inventory are paraphrases and condensations of the ideas expressed in the transcript. The numbers in brackets refer to the questions from which the ideas were drawn.

1.0 Rationality

1.1 Scientific conclusions are based on consistent and repeated experimental results (5)
1.2 A reasonable scientist will sometimes retain a theory despite a disconfirming experimental result (11)
1.3 Hypotheses are generated through deducing consequences from theories (5)

2.0 Objectivity

2.1 Experiments prove or disprove hypotheses (5)
2.2 Facts are objective (6)
2.3 Observation is shaped by our ideas and background (1)
2.4 Observation is a true picture of reality (6)

3.0 Discovery

3.1 Discoveries are based on a wide network or pyramid of other knowledge (3)
3.2 Discovery is deductive (6)

4.0 Growth of Knowledge

4.1 Theories expand to include increasingly wide ranges of consequences (5)
4.2 Theories account for all current relevant data (5)
4.3 Growth occurs through theory reduction (5, 11)
4.4 Growth occurs as a consequence of new insights and changes in perspective (1)
4.5 A change in theory is a change in how a thing is seen, not in how it really is (11)

As is clear in this inventory, Mark holds many views which taken together appear inconsistent. For example, item 2.3 appears to deny the ability to hold 2.4 but concurs with 4.5; 3.1 seems to collide with 3.2; and 4.2 casts doubt upon 1.2. Such results are not unexpected. The exposure to a variety of
teachers and other influences with a variety of implicit philosophical positions on a wide range of philosophical issues is such that it would be unreasonable to expect internal consistency of Grade 12 students. Further, it would appear that some of these ideas are contextually dependent in that the references given for conflicting views are from widely divergent sections of the transcript. This becomes even more clear in a further analysis of Table 5.2.

2.0 The Context Effect

In returning to Table 5.2, attention is drawn to the last two columns in which the summary of student responses by question is given. There appear to be two groups of questions involved in this test. Firstly, a group of questions (1, 4, 11) relate to science and its methods, and a second group (6, 9, 10) approach the relationship between science and society. These two groups will be examined separately.

3.1 Science And Its Methods

On the first question (1) a total of eight answers were categorized with two being Weltanschauungist and six Empiricist. While the question directly asked if there was any topic about which science knew everything, the interviews pursued the related point of whether this was possible in principle. Those classified in the Weltanschauungist position affirmed the belief that this was not the case, principally due to the continuing emergence of 'new aspects' and 'new perspectives'. They both agreed that these ways of perceiving were somehow related to a person's cultural environment.
Six students were classified as Empiricist on the basis of a weakly advanced claim that science could somehow achieve this state of total knowing. Reservations were stated in terms of how much time and or effort would be required. One student stated that such a capacity was beyond mankind's abilities, but held that the situation was not impossible in principle.

On Question 4 even more uniformity was attained. This question raises the issue of the relationship between the sciences. Here one of the student's was classified as Weltanschauungist while eight were Empiricist. All eight claimed that the basis of the relationship was on the continuity of observation, principles, and or ideas. Many indicated a decidedly reductionist view on this issue. One student claimed that the sciences were unrelated due to the nature of the various types of phenomena they study.

Question 11 dealt with the issue of theory succession and the effect of recalcitrant data. On this question six students were classified Weltanschauungist and one was Empiricist. The Empiricist took a very hard falsificationist position and insisted "The facts are there - the theory's the thing to change - not the facts. The facts will always be there. They've been proven... The facts are hard - the theories are flexible." The six Weltanschauungists all took the position that in the face of recalcitrant data, theory should be modified to take account of it. This minimum claim (paralleling Kuhn's 'normal science') was in all cases but one, scored as a weak Weltanschauungist response. One could argue, though none did, that theory
modification is a form of theory reduction in that a theory T is being reduced to a more general theory T1, the recalcitrant data being taken as evidence for the theory in the very closely related domain. On this argument the weak forms of both positions take an identical stance with respect to the handling of apparently disconfirming evidence. The single student who was classified as a strong Weltanschauungist made a clear distinction between the 'normal' and the 'revolutionary' response to anomalies. The remaining six students were classified Weltanschauungist primarily on the seeming plausibility of their assertion of the 'normal science' interpretation. In retrospect, it would appear that the distinction between this position and the weak form of the Empiricist position is slight; so slight, in fact, that given the very general nature of the interview data on this issue and the fineness of the distinction being drawn, they might well have been classified as weak Empiricists. In any event, it is possible that under more detailed and specific interviews, at least some of the students would have demonstrated a more clearly Empiricist position.

Overall, it would appear that on this group of questions relating to science and its methods, the students interviewed were predominantly in, or leaning in the direction of, the Empiricist school. Different results obtain in the analysis of the science and society group of questions.

3.2 Science And Society

The first question (6) in this group addresses the issue of
the role of scientists in public affairs. The question asks how we are to evaluate the comments of a scientist in the area of nuclear proliferation. Of the nine students, seven were classified as Weltanschaungist and two were Empiricist. The Empiricist students both alluded to the qualitatively better analysis which a scientist would bring to bear in his or her comments on international relations. As Tom put it: "...see, if they're a scientist they must have some sort of know-how and knowledge.". Amongst the Weltanschauungists, the common response pointed both to the inability of scientific analysis to consider all important aspects as well as the idea that scientists' results on this type of issue can be highly affected by their political and scientific values. Kerry points to the first problem in saying "...you'd have to consider the possible environmental effects of reactors themselves and of the politics of the country you're giving them to. If they're going to make a bomb with the by-products, which I think India did, you'd want to consider both possibilities". Peter indicates the other problem "...his judgement will be, how would you say, prejudiced if he has his own views...He'll try and find reasons to give it to other countries or find reasons not to give it to other countries".

On the second question (9) in this group the split was five Weltanschauungist and three Empiricist. This question dealt with the role of science in deciding on the construction of a coal-burning electric plant. Each of the Empiricists believed that scientists could fully determine the effects of such a plant. The five Weltanschauungists shared a common belief that while
science could provide some of the answer, the issue is far too complex in that there would be many non-scientific effects which would have to be considered.

The third question (10) related to the function of public input and regulation of the research efforts of science, specifically in the area of recombinant DNA. Public regulation and supervision was seen as distinctive of the Weltanschauungist position. Five students supported this position while four believed that scientists alone should determine the thrust and direction of research.

In this area a total of seventeen Weltanschauungist and nine Empiricist responses were classified. In contrast with the 'science and its methods' question group, the students here are predominantly Weltanschauungist in orientation. This difference, arising from an analysis over students by question, points to the interesting questions of its genesis. It seems plausible to suggest that at the end of twelve years of schooling students have absorbed a generally Empiricist orientation with respect to the nature of science as a knowledge generating activity yet their beliefs about the relationship between science and society may have been effected by the environmentalist lobby over the past fifteen years. A further discussion of this issue is contained in Chapter 6.
Chapter 6

Conclusions And Recommendations

1.0 Overview Of The Study

This study established three substantive questions as its guiding problems in Chapter 1. While they may be viewed as the warp upon which this study was built, the woof of a meta-question concerning methodology has been woven throughout. In this chapter the substantive conclusions which can be drawn will be reported within the web of the conclusions drawn with respect to the meta-question. The two have been inextricably bound since the project's inception and in this sense, each points to the other.

The first problem posed was essentially philosophical in nature, it asked whether the nature of science might be understood within two generalized typologies which would simultaneously reflect the diversity of the discipline, and yet be sufficiently differentiated that they might serve as an analytic tool in the understanding of student belief. The plausibility of isomorphically mapping student belief against philosophical belief summarizes this question. In seeking an answer to the question a wide range of the philosophical literature was consulted. The results were critically dependent upon the work of Suppe and Brown.

The second question was directed at the possibility of analyzing a group of multiple choice items from the B.C. Science
Assessment on the basis of the two generalized typologies. Items were selected that related to the literacy goal of the Assessment instrument and were then successfully analyzed into the two proposed typologies.

The third question asked how many students were able to be classified philosophically on the basis of the typological analysis. The data from the B.C. Science Assessment were subjected to this procedure.

The questions above were approached in the conceptual and empirical components of the study. The third component, a clinical one, sought further elaboration of how students understood the nature of science and the reasoning used in arriving at their positions. This was a very exploratory component. Interviews with 9 students were conducted.

The fourth question asked what methods might be employed in the assessment of student understanding of the nature of science. Conclusions which suggest possible directions are drawn in this chapter as well.

2.0 Substantive Conclusions

Chapter 4 elaborated the philosophical grounds on which it may be fairly claimed that two generalized 'families of belief' or schools in the philosophy of science may be identified and described. Given that this study sought to develop two coherent views of science as an analytic tool, and that they therefore had to be sufficiently general as to be useful in analyzing high school students' beliefs, it is concluded that the typologies
presented represent two defensible options. This by no means can be interpreted as saying that they are the only two. Indeed, there are a number of avenues still to explore such as the renewed interest in realism as well as the renewed expression of scientific faith, seen in the broad support for the most recent science fiction movies, to identify but two.

The second substantive question was directed at the possibility of utilizing typologies to chart the various options on multiple choice tests of scientific literacy. Some difficulties were encountered in achieving this goal. Partly they may be attributed to the use of existing items which were not intended for this purpose. As reported in Chapter 5 (section 2.4), on items for which a single distractor represented both positions, students with differing views did choose the same answer. The interview data substantiates the claim that they did so for differing reasons. Likewise, on those questions which had differing distractors, 80.7% of the students chose the distractor appropriate to the pattern of belief identified in their interviews. Both these results point to the viability of creating instruments specifically to measure students' differing understanding of the nature of science. Again, this conclusion must be stated in weak form because of the exploratory nature of this study.

The third question also points in useful directions. The reported results of this analysis (Chapter 5, section 1.0) indicated that 6.35% of the sample were found to have selected the Empiricist response pattern and 1.08% selected the
Weltanschauungist pattern. It would appear that there is evidence to support the conclusion that high school students do not hold fully consistent positions. This conclusion however, is moderated by the relative weakness of the analysis. Again, the weakness lay in the use of the Science Assessment items. It is suspected that more conclusive results would be obtained with a study based on items developed specifically for this purpose.

3.0 Methodological Conclusions

The methodological meta-question can be answered more enthusiastically. The overall conclusion is that the process undertaken in this study is sufficiently promising to warrant further work in this area. It is definitely not in a finished form as yet but the general outline can be seen. In outline, the methodology proposed is as follows:

1. Families of belief or schools within the philosophy of science can be identified in the literature or through other sources, which are sufficiently distinctive as to be meaningful to students at the high school level.

2. These families should be cast in a general form which allows their mutually salient issues to be readily identified.

3. These issues may then be utilized in the construction of differentiated multiple choice items.

4. The questions may then be validated and revised through such techniques as the analysis of student interviews.
5. The final version may be used to identify areas of inconsistency within student patterns of belief thereby providing direction for further individual study or curriculum development. Research in this tradition can be on two levels. As a classroom instrument, its results could aid the science teacher in structuring his or her lessons in such a way as to raise issues in which the class as a whole demonstrates a lack of understanding. Moreover, individual results should readily lead to prescriptions for individual study. On the second level, as Aikenhead (1973) has concluded, the generalized use of such an instrument will be highly informative in terms of curriculum design and revision. As the B.C. Assessment rated Grade 12 scientific literacy as marginal on the whole, it is clear that such work needs to be undertaken.

4.0 Recommendations For Further Work

The claim has been tentatively advanced that the methodology of this study may be helpful in further research. It has been pointed out that a number of problems were encountered here relating to the use of pre-existing items. It is recommended firstly, therefore, that a study be undertaken involving the development of a specialised instrument along the lines outlined in the previous section.

A second suggestion arises from the reported context effect i.e. that student beliefs may be more related to the issue under discussion than they are to each other. Elkana (1970) has suggested that at least as far as science and its methods is
concerned, most of the curricula deriving from the mid and late 1960's project an implicit Empiricist notion. Specifically, he says that these curricula and their associated teaching methods assume that 'after the Einsteinian revolution and the new attitude of relativism with respect to the value of scientific theories, there is only one thing which remains certain and unchanging - the scientific method.' (Elkana, 1970, p.22) The second recommendation is that more detailed study of the structure of student beliefs be initiated with the hope of identifying some of the factors related to their genesis. Roberts and Russell (1975) review a variety of approaches which appear to lead in this important direction.

A third and final recommendation is in the area of classroom resources and practice. Further work is required in the development of curriculum materials and strategies which are based on an appreciation and respect for the differences in student understanding of the nature of science. Roberts and Orpwood (1979) have demonstrated that curriculum may be designed in such a way as to reflect a variety of emphases. In particular, their work in developing three versions of a unit on the properties of matter reflects an emphasis on the nature of science (Blue Version), skill development (Red Version), and science and society (Blue Version). It is illustrative moreover, of a methodology of curriculum development. As they pointed out, the three views are

...firstly, evidence that the same science unit can be oriented towards different sets of objectives. Secondly, they can serve as an
example or pattern from which other multiple
versions of science units can be developed.
(Roberts and Orpwood, 1979, p. 8)

Aikenhead's (1976) 'Science: A Way Of Knowing' demonstrates a
similar point. It is suggested that within the 'understanding of
science' objective, parallel curricula may be developed which
are illustrative of at least the two typologies presented in
this thesis.
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Appendix A

The Questions Used In This Study

1. About what topic do scientists know everything?
   A) clouds.
   B) stars.
   C) trees.
   D) no topic.

2. Astrologers use the position of the stars and planets at the hour, day, and minute of a person's birth to predict his future. Which one of the following statements regarding this practice would be accepted by scientists?
   A) The modern astrologer can now predict one's future more accurately because better telescopes are in use.
   B) There is no evidence that astrologers can predict the future of an individual on the basis of stars and planets.
   C) Some astrologers inherit the ability to understand the stars from their mothers or their fathers.
   D) Study and long years of training in astrology make an astrologer's predictions of one's future more accurate.

3. Which of the following statements best describes the connection between science and technology?
   A) Technology involves the practical applications of scientific knowledge.
   B) Science depends on technology for ideas and the organization of experimental work.
   C) Workers in science use the laws and principles discovered by workers in technology.
   D) Technology is the part of science that deals with mechanical problems.

4. Are biology, chemistry and physics related? They are:
   A) not related because they are built on different sets of fundamental principles.
   B) related because observations, principles, and ideas of each field have connections with the other two.
   C) related because mathematics serves to unify the sciences.
   D) not related because biologists, chemists, and physicists study very different natural phenomena.

5. A student wrote the following note on a laboratory project: 'Using a cork-borer I obtained several cylinders from a large potato. The cylinders were 7 cm long and .5 cm in diameter. I kept them on a dry plate and measured them again on the following day. I found that all of them had become shorter and thinner.' The student then put the cylinders into a beaker of tap water and wrote: 'If I measure them tomorrow I shall find that they have all returned to their original size.' In writing
this last sentence, the student was:
A) making a statement of fact.
B) drawing an observation.
C) drawing a tentative conclusion.
D) describing an experimental procedure.
E) making a hypothesis.

6. In discussing the problem of nuclear proliferation, a famous scientist declared that Canada must provide more Candu reactors for developing countries. What is the best evaluation we can give to this scientist's statement?
A) His conclusion is probably right, since he approaches the problem with a scientific attitude.
B) His conclusion is probably wrong, because scientists seem to be trying to destroy the world.
C) His conclusion and reasons are probably correct, because scientific results are the most reliable kind.
D) His conclusion and reasons should be weighed according to his knowledge of international affairs.

7. It has often been said that published reports of scientific research are generally very accurate and honest.
A) This is true because scientists are very accurate and honest people.
B) This is true because only one answer can be correct in science.
C) This is true because reported results can be checked by other scientists.
D) There is little basis for this claim.

8. An example of a scientific model is: 'The atom is like a miniature solar system composed of electrons in orbits, and in the centre, a nucleus containing protons and neutrons.' Which one of the following statements about scientific models is not correct?
A) They are man-made constructs and may not represent reality.
B) They consist of a relatively small number of assumptions.
C) They represent what scientists could see with very powerful instruments.
D) They are tentative and may be modified or discarded.

9. A coal-burning electric plant is proposed in your area. The power plant will reduce the cost of electricity as well as prevent future power failures. It will also discharge heat into the environment and cause some air pollution. What should be done?
A) Build it. You can save money.
B) Build it. It will be good for the community.
C) Build it. You will have all the electricity that you need.
D) Don't build it since it will pollute the water and air.
E) Don't build it without first determining the
effect on the environment.

10. Which of the following is the most urgent problem with regard to recombinant DNA research?
   A) Ensuring that controls are effective and enforced.
   B) Keeping scientists from fooling with nature in this way.
   C) Keeping government from interfering with scientific research.
   D) Making sure scientists don't create monsters in their laboratories.

11. When many new facts are discovered which do not fit a scientific theory, scientists will usually ask themselves:
   A) Shall we throw out the theory since the facts do not fit?
   B) Can we change the facts a little so that they fit the theory?
   C) Shall we keep the theory as it is, since the new facts don't help it?
   D) Can we change the theory a little so that these new facts will fit in?
APPENDIX B

A Transcript Of Mark's Interview

Age: 17 years 9 months

Notes:
(1) I = Interviewer
    S = Subject
Mark's Interview

Question Number One

I: Now on the first question you have chosen answer D and what I would like you to do is to try and amplify on why you've chosen that answer - what your reasons are for that.

S: Whenever we've had science classes we've always been led to believe that there's always more information than we can gather. It's hard to get everything because you can't take everything into account - you can't look at something and say that you know everything about it because you may have not looked at it in an aspect that you haven't realized yet that exists. So that could bring forth further information so you would - it would add to the topic.

I: How is it then that people come to these new ways of looking at things?

S: Well I think it's just different ways of each individual person - a person has a different way of looking at a specific topic. I can describe an object in one way and another person can see it in a totally different light. So I think it depends on what the person, his upbringing and everything like that or what is effective in his outlook on things.

I: Do you think that there will ever be a time at some time in the future where we will know everything about even one topic?

S: It's possible. I don't know because I don't know how many different ways you can look at an item or at a particular topic. We may think that we know everything, all the possible angles but there may be a few, one or two that we haven't discovered. So it could continue on, I don't know.

I: What would be your best guess?

S: That we wouldn't know I don't think.

I: Ever.

S: No.

Question Number Two

I: In question 2 you've selected answer B and I was wondering if you could explain that a bit further. Why is it that a scientist would agree with that statement.

S: Well the random - it's not random movement of stars but when a person is born - this is the way I feel, that I don't see that they can, that the way the stars move affect what you're going to do in your life. I don't see any connection between the two. I'm sure we're part of the whole thing and you can look at it like that but how two bodies affect each other or millions of bodies affect another body - we can do two body projects with physics but we get to three body projects and how they affect each other it becomes unknown. It's very complicated and you talk about all the stars and how they affect one person, well we're such a small infinitesimal piece in the universe that how can that - it may have an effect but I don't think that there's strong evidence to support that a movement of stars does affect our lives. I don't if that answers it.

I: What you said was that there was no strong evidence to support that. Does that mean there is some evidence to support astrological predictions?
S: I really don't know. I don't know whether I meant strong evidence. I don't think there's anything really that I know of. There might be but I don't know of it. I'm not really that well versed in the topic or have a lot of knowledge. I personally don't believe in it but I don't know if there is evidence really to support it.

I: Do you think that somebody who is well versed in astrological knowledge and so on could get better at making predictions with more training and better training?

S: Well because I don't believe in it and I don't see that he can - that they can relate the two so I find it hard to believe that practising something like that that you can get better at it. I find this kind of hit or miss. Any kind of things that I've read in the horoscope that sometime is seen in the papers. they seem very general about things - it can include a wide range of things that can happen in one day so you're maybe taking a wild guess and just putting it in general terms so that it might fit everybody's lifestyle.

Question Number Three

I: Let's go on to question 3 then and in question 3 you've selected answer B. What I'd like you to first of all think about is why you didn't choose answer D.

S: In terms of B - like why I selected B over D.

I: No. Why you rejected D. What were your reasons for not choosing D.

S: Because technology also - technology is - you incorporate scientific ideas into technology but then you come up with the technological problem part of it may come up with mechanical problems but then they also come up with theoretical problems that weren't first encountered in a scientific theory and then put into the technological phase so just saying they're based exactly on mechanical problems alone wouldn't seem to be correct.

I: And why didn't you choose A.

S: Again because it is practical application in scientific knowledge but it isn't - it just isn't the application alone of that knowledge - you're also bringing in other technologies into it if you're building one thing you've based it on, it's like a pyramid - you've based it on all sorts of other knowledge. It can be the science and technology mingled together that is helping you to apply the scientific knowledge but it's not just the scientific knowledge alone. It's not the practical application of the knowledge alone.

I: So you're saying that technology is not just the application of scientific ideas because it involves other ideas? What other kind of ideas might be involved other than scientific ideas?

S: Well the technical ideas, a scientist may make a theory and put it into practice but there is technical reasons why it shouldn't work that he hasn't thought of. Those are - as I understand technology it's the bringing together of all the ideas to form to put into use scientific knowledge that comes to light through work in theory. But theory work can be applied, just the practical part, but to apply the practical part you've also got to apply the technical knowledge behind it so that it. I feel that it's the two of them together that make up the application
of the theory. The technical knowledge and the scientific - the practical, technical and practical scientific that make up the two.

I: Then could you explain why you chose E?

S: A scientist takes his ideas and it's first a theory and he may prove it in the lab but he has to apply it into a broader sense - into "the real world" here like outside the laboratory situation where he may not have taken all ideas into account - all the factors. So when he then takes it to the technical aspects of it he has to - he brings to light further ideas which then help him to reorganize his theory around the technical problems so that it further defines the theory and makes it - well not a law but - makes it a fact I guess. I think that's what I had in mind.

Question Number Four

I: Moving on to question 4 you have selected C. Could you explain that?

S: My personal outlook on it is that with the chemistry that I've had it seems to be that all chemistry is, can be defined in terms of energies involved between the reactions of atoms and molecules and things like that. Biology again is the chemical reactions of those things. So if you can go from biology to the chemical aspect of it, of how the chemicals react to one another, down to the chemistry which is the energy and then physics is the study of that energy and you define that energy in terms of mathematical terms. And I think they interrelate that way so mathematics is the backbone of the three of them although you don't study the mathematics so much in the biology course.

I: You've indicated that you see the three sciences being related by mathematics and you've also suggested that in a sense it's the conceptual level of understanding of the principles that are consistent right through as well so that you study energy in physics, you've studied the energy of reactions in chemistry and you study the reactions of chemistry in biology. If that's the case could you explain to me why you were not able to accept answer B.

S: I don't really know. I think the mathematics has stood out in my mind whenever I've thought of this before. It seems to be the one thing. Principles are the same. It's very - they're almost the same. Looking at it again they're almost the same answer because the principles can again be defined in terms of the mathematics and the principles and ideas which - they're all based on the mathematics. If you come up with an idea or a reaction between two things then the reaction, if it occurs, can be defined in terms of mathematical sequence and the idea then if it's not an idea anymore becomes a principle and the principle is therefore defined in terms of mathematics.

I: It seems very much like you're viewing mathematics as sort of a working tool of science. Sort of like a microscope or a telescope.

S: Yeah it's something that helps to define the knowledge that we gain. It brings it to the crux of the matter, the math behind it.

I: So it's a language of science. (S: Yeah) And as a language of
science then you see it that that's what holds science together?
S: Yeah, I think so.
I: More so than the inter-penetration of the principles or the...
S: The way the principles work together is fine but I feel that the mathematics behind is what holds it together. The principles may weave it, but the mathematics provides the backbone to the whole thing.

Question Number Five

I: Moving on to question 5 you've selected answer E and what I'd like you to do is distinguish then, between E and C.
S: Making the tentative conclusion he's saying that this will happen but not proved experimentally yet. He's saying that before it happens. I think the hypothesis is that it hasn't happened yet, but it may, and then he's got to prove it in order to make the conclusion. The conclusion shouldn't happen yet. It can't be a conclusion until something's happened. A tentative conclusion I think is something that you've - you've come up with a conclusion after an experiment but you're waiting to prove it again through further experiment. And this here he seems it's only going to be one experiment so that it should be a hypothesis until it can be examined again.

I: Where would the hypothesis come from - why would somebody come up with a hypothesis like this?
S: In a situation like this? (I: Yes) well I think behind it he's saying that okay the potato dehydrates - loses its water so it shrinks. So if I put all the water back in it should come back to its original size. So the hypothesis is "After dehydration when you add water it should come back to the same size" but does it? So he's got to therefore go and prove the hypothesis two or three times before he can say that is a conclusion from the lab or from the experiment.

I: Is the hypothesis proved if you do the experiment say two or three or say ten times and each time the potato increases to its normal size?
S: Exactly the same size. I'd say the hypothesis would be proved.
I: And then having proved the hypothesis what do you have then?
S: I'd say you have the conclusion that after dehydration and when you rehydrate it - add water again - it does come back to its original size. So that can be a conclusion. It can be drawn from the experiment.

I: Is that also a theory then? Or does a theory come from somewhere else and where does a theory fit in.
S: I think a theory and hypothesis are the - the theory. I'm just sorting it out here. The theory is actually not having done it at all. You can say that this might happen. You can draw, make a hypothesis after - you can say okay it does go down to one size now I'll say that maybe it will come back to the next size. That's a hypothesis and then you can draw the conclusion after proving the hypothesis in experiment.

I: Does the conclusion then have any bearing on the theory?
S: The conclusion can disprove, or it can cause him to scrap the theory or it can cause him to modify the theory according to whatever - what the conclusion actually is. If the potato only came back to half its original size then the theory would have
to be modified. But if it came back to the original size then he could say yes this theory can become a conclusion and a fact.

I: So a theory that's proved then - it becomes a fact or 

S: A theory that's proved becomes an idea that you can say well it's most likely that this is going to happen. You can draw the conclusion and say okay when you relate it to something else say you're doing it with an apple you can say this should happen because the potato did this. So the theory becomes something you can base further or another conclusion because of the theory and can then be applied to other situations.

I: Is that when it becomes a theory when it can be generalized - you can develop hypotheses for other situations?

S: Yeah I think so. When you can apply the theory in general instead of specific with just the potato you could say apply to all the fruits and vegetables and then say well this theory if it applies for all you draw the conclusion from the one. And the theory if it applies for all of them you can say that okay that theory does work in general and if it works in general then it becomes something that is almost fact until you prove that it doesn't with something else. Does that make sense?

Question Number Six

I: Hmm. Let's move on to question 6 then. In question 6 you selected D and I'd like you to explain the reasons for choosing answer D.

S: Can I do it by eliminating the other ones? (I: Sure) the approach - the scientific approach is not always correct and maybe the clinical and the way that it should happen in a laboratory but outside it may not happen that way. In the "real world" it may not in fact have that reaction that you got in the laboratory. So it's not always right. Scientific approach is not always right in the "real world".

I: Could you explain that one a bit more? Why is it that scientific ...

S: You can't say that his conclusion is right just because he's a scientist. Because he's a scientist he may approach things in a scientific - with a scientific approach - a manner which he carries in the lab but the lab manner may not really apply to the real world.

I: How could it not apply to the real world? What would prevent it from applying to the real world?

S: Other influencing factors like --- in the lab it's - you don't have the influence of other people what other people are thinking. It's just an objective look at what happens - it's an idea of what happens. But on the outside there's other influencing factors like other people and a thing like Candu reactors, other people may not want it to happen or other people may have reasons that he hasn't thought of for this not happening. For instance, he says that - in here it says that he should but his conclusion may not be right because well we gave the Candu reactor to India and it became a member of the nuclear bomb club - very elite. So just because you approach it with scientific manner it may not be right because there may be further implications outside the scientific approach.

I: So the scientific approach then can't be applied to all problems - is this what you're saying?
I: I don't think so. Because there are abstract ideas that may influence it that can't be taken into account with a scientific approach. That may be contradiction.
S: No that's okay. Let's move on to E then.
S: Okay, I don't know that there's any proof that scientists are trying to destroy the world so I can't say that his conclusion is definitely wrong just because of prejudice — my prejudice that scientists are trying to destroy the world.
I: Do you hold that prejudice?
S: No. I'm just saying in the sense that trying to refute it...
I: And C?
S: Science again relates to A. "scientific results may be reliable" but they may not necessarily be the most reliable for a given situation. I don't know that I can think of an example. I'm trying to think of something that could approach it in two different manners. His reasons are — I don't know — it was just a feeling that I had that the scientific results aren't always the most reliable. Okay, if the scientist has brought some of his own feelings into the conclusion then his ideas may not necessarily be reliable because he's allowed his prejudice to be part of the conclusion.
I: Do you think that happens very often?
S: I don't know whether it happens very often. It shouldn't but it may...
I: Why shouldn't it happen?
S: Because I feel that a scientific experiment or a scientific conclusion should be arrived at objectively and if it's arrived at objectively you get a true picture of what is actually happening instead of a person's pre-judged opinions coming out on the paper instead of what actually happened.
I: Let's go back to your response to the first question when you said that we can never know everything about something because there will always be another way of looking at it and I think you also said that that way of looking at it will be partly created by how they were brought up, the way they were raised and so on...
S: That's what I mean. But I mean that because a person has been brought up in a different way he'll have a different way of looking at the problem so that may give him a different insight. So if they've got a different insight that somebody else may not even have they can then look at that insight object — try and look at it objectively and write what they record.
I: Why would it be just try to be objective?
S: Well it depends on the person who's looking at it.
I: Is it right to be objective — is it possible to be objective?
S: I think it's possible to be objective but I think it's difficult. I know that when we do labs here, if I can apply it here, it's difficult — you know that something should happen but your results show that it doesn't and therefore you tend to disbelieve the results.
I: Why would you do that?
S: In our case that we know that this reaction should take place but in our experiment it didn't. So we try — we say no that couldn't be right because it — we've done something wrong. You tend to believe something that has been backed up or that has happened before instead of saying "yes I am right", I try and
I: Do you think that scientists do that? Try to get results that are sort of concurrent with everybody else's?
S: No I don't think they do.
I: They don't. You do that as a science student?
S: As a science student if I know that something should happen but the things we look at we know what happened before and it should be a set way that they happen. But my interpretation of a scientist is somebody who is looking at something that is unknown so he can't base his results on anything yet. He can base it on theories that can be applied in general and if those theories are brought out, alright. But if they don't bear out under the observations that he's made the theories might have to be modified so that if it is objective the theories can be changed because in fact this did happen where the theories predicted that this might happen, that something else might happen, contrary to what did.
I: Would it be possible that the scientist saw something happen, some event 'x', that another scientist when observing the same thing would see differently?
S: I think that's possible.
I: Then how would we know that it was time to change the theory if you look at event 'x' and you see 'y'.
S: Well if it just happened in just 'x' and this only happened once and this only happened once you can't change the theory yet because . . . .
I: What if the scientist always sees red when he sees event 'x' and the other scientist always sees yellow when he sees event 'x'.
S: I would say that they would have to be just because two people saw two different things — it should happen more than just those two people looking at it.
I: Imagine that there's fifteen scientists who see red . . .
S: And fifteen see yellow
I: How could that be? Are fifteen of them not being objective?
S: Not neces - I don't know - I really don't know. If it's fifteen-fifteen it seems odd that if you can base something on a theory that this should happen — it should turn out red or it should turn out yellow how it can happen in both terms. So maybe it should be approached from a different angle to see to try and prove that either it happens in red or it happens in yellow or this shows red and this shows yellow but try and approach it from a different angle. Maybe the angle they're approaching it is too scientific or is too . . . . It's only one way like tunnel-vision and you do in one way and you always do it in one way. So maybe there's some influencing factor.
I: Does it have to be that there's only one right answer there? S: Not necessarily I don't think. I don't know I might be contradicting myself. Again . . .
I: Would that bother you?
S: No. Because again if there's more than one answer then like we don't know everything about that subject and we come back to just do we know everything about everything — do we know everything about one topic. If there's no right answer then how can we know the — come up with a definitive answer and know everything about that one subject?
I: You said you might be contradicting yourself and I asked you
whether you saw that as a problem and you just said no. But you
did mention it and I'm wondering why you mentioned it.
S: Because I'm not sure of what I - I'm not exactly clear on what I
had said but it seemed to me that I remembered saying something
that might contradict...
I: That would be okay for you to contradict what you just said?
S: I don't know. I'll stop for a second.
I: Sure.
S: To contradict one's self it - you should examine both one reason
from the other and then maybe one or the other contradictions
can be thrown out. And I don't know - I can't remember what I
said now, so why I contradicted myself. I don't know the reasons
behind it.
I: But in and of itself you would try to confront it.
S: If I could find the contradiction I wouldn't mind because then
I'd have to modify my feeling. I'd try and examine the two
reasons which contradicted each other and I'd try and say "Okay
now which one was right in my mind and which one was wrong".
I: You'd try to eliminate one...
S: Eliminate one.
I: So that you in fact wouldn't settle for contradicting yourself
for being contradictory.
S: In the end I don't think so. I'd want to try - I wouldn't want
to be wishy-washy and say one thing here and another thing there
that contradict each other. I'd want to have one set path.
Question Number Seven
I: Let's take a look at question 7. In that question you selected C
and I'd like you to say something more about that.
S: My personal opinion is that when a scientist publishes a paper
it is done - he has examined it from all angles and this is what
he has come up with --- and maybe a new revolutionary idea. And
when he publishes it he's looking for other people's input so it
should - it will be accurate and honest because it will be
subjected to other people's - to other scientist's scrutiny, and
when they're scrutinizing it like why would he want to risk his
professional opinion on a lie or a falsehood if it's going to be
disproved by others examining the concept. I don't think that -
that's like personally destroying himself and that he'd lose
credibility so his paper wouldn't have any - may not have the
same effect and may not be recognized by as many people.
I: Have you read any scientific publications?
S: I'm not really sure - I think I have. I've read Scientific
American and some of the articles in there.
I: Is that where scientists publish their research?
S: Not necessarily no. That's just one magazine but I think - isn't
it - they publish them in university papers. Mr. ---- told us
about some of the U.B.C. profs publish their ideas in papers
and I think that they're looking for other people's opinions or
other people's views on that topic or their observations on that
topic so that they can further modify their idea if it needs
modifying - if the facts bear out. If the facts do bear it out.
I: How do you suppose an article gets published? Does somebody have
to agree with it before it gets published? Or do scientists
publish things that they don't necessarily agree with?
S: I think for scientists to publish something he would have to
believe in it but he may not have to believe in it completely. He'd still have to have one part of him open to maybe contradictory evidence – contradictory evidence coming in from another quarter.

I: Who would decide whether a paper would be published?
S: I think – isn't it – it's, I may be wrong, it may be done by a board deciding on the merit of the paper.

I: Who would be on the board?
S: I don't know. Colleagues?

I: Other scientists?
S: Other scientists, colleagues of the prof or other scientists involved.

I: So would other scientists have to agree with him in order to publish the paper?
S: I don't think so. They'd have to judge it on its merit alone not on their personal feelings. If they say no that can't be right but he's presented evidence that is contrary to their belief I'd say that they'd have to publish it because there is the possibility that they could be wrong.

I: So do you suppose that journal boards, editorial boards do that? That journals are often full of things which...
S: No I don't think so. I think that – I'm saying that that's the way it should be done but I think in other ways

I: What would you think is done?
S: It reflects the feelings of the board people because they're in it to make the money and if it. If they're high up they've gotten there because their opinions have influenced people and their opinions may be those that – those that they feel are right and they may be single minded in that. They should have the open-mindedness to say maybe they might be wrong but they may not.

I: So if that's what you believe then how would contradictory articles get published? Where would they publish them?
S: Maybe somebody who has that open-mindedness and has the power to fight the rest. Like maybe the head of the board may agree with the guy and he may publish it even though the rest of the board members do not agree that it should be published.

I: So it would become published by some kind of fight.
S: I don't know if it's a fight – just a little bit of weight pulling on strings. You'd have to believe in it – for the head of the board to say "yes this is right I want it published" he'd have to believe in it and he'd have to have the belief behind it that even if he's – he may be wrong but he has the personal belief behind it that it doesn't matter what others are saying at this moment, he wants it published because he believes it has merit to the scientific community, and merit which can add to the knowledge of the scientific community.

I: The scientific community then, is that – who is that? What do they do?
S: My vision of the scientific community is the people that have the – can do the working behind in the labs. They influence the way our society moves like technological advances. They're the people that bring about the new ideas and the new theories and bring about the technology and things like that. They're not just one group of scientists. They're everybody. It's the ones – the people that are involved with the sciences and the
technology and maybe the management and all that also. They have
to decide on the merit of that paper.

Question Number Eight

I: Let's go on to the next question, question 8. I want you to look
again very closely at the question and at the four possible
answers and I would like you to explain to me why you selected
E. So just take a couple of seconds there.

S: In the terms of this - if I can use a scientific model, this is
the one I based my reaction on. My assumption - if they try and
limit the assumptions but there are many assumptions that go
into the making of a model that have to be proved out into
scientific fact. That the atom is a proton neutron with an
electron shell around it and then the model shows us that as a
tall like the ones that we have that I've seen it shows a stick.
Okay we're making an assumption that they are in fact like that
and they do react in that way but even though we can't see it to
prove it there are ways that prove that it may look like this
but you can't see that small - you've made the assumption that
this is the way it should look so the idea of the model is to
give you some working - some basis - if you can't see it you
can't see the structure of nucleic acid just sitting there and
you can't lock down that small so the idea of the model is to
give you something to base your ideas the way that this model -
this works - why it works this way. There may be assumptions
involved in that. I may have read it too quickly. I'm thinking
about it which may be right.

I: Would you like to change your answer?

S: Okay. I'm not sure that I do yet.

I: Do you want to look at the other ones then and see whether....

S: Yeah. Okay I'm going to have to do this by process of
elimination again starting with D. Models are tentative and they
are subject to being modified and discarded just like theories
because if a certain substance doesn't react in a way the model
indicates that it should. If the substance reacts in one way and
the model indicates another the model may have to be modified
slightly so that it may be concurrent with those seen. That
eliminates that one. This is going to take a bit here....

I: So problem. Take your time.

S: Okay - I'm not sure - I think there's something called a
theoretical model. You can build a model around a theory to try
and prove that that theory I think - I don't know whether
Einstein built the theory of what space meant around maybe a
plastic sheet with a large mass in the middle to explain
gravity. That's one way to build a model around his theory. The
thing had to be proved. So it may not in fact represent reality
but it is a manmade concept so I'm having trouble with this
because some of these are the same.

I: So you agree it may be a man-made concept and it may not
represent reality.

S: It may not represent reality in fact until it's proven. I'm
going to change my answer to I don't know because some of these
"very powerful instruments".... If you build a model of an
atom. The atoms are so small that the light waves don't reflect
- you can't see that small like in terms of conventional
microscopes. I don't know how electron microscopes work. I don't
I didn't know the theory behind them or even smaller very powerful instruments. We don't have any that can see that small so I don't know whether that in itself is true but I don't have any evidence to say it's not true.

I: Think of what we said when you looked at A. You said that a model may not represent reality. Now C says that it does represent reality - it represents what scientists can see if they have very powerful instruments. So those two have to be locked at very carefully.

S: Again if it doesn't represent reality you're going to have to modify it so that it might. You've got your theory - if you build your model around the theory and then the theory, the model doesn't work and the theory does or life doesn't work the way the model does the model may have to be modified to the way life works. So you initially have your model, you may look at, you may look microscopically or with a powerful thing and it may not initially it doesn't look like this and that may be the reason that it doesn't represent reality. So that could be the one - that could be a reason why it doesn't represent reality so that when you look at it, it then it may look again like reality. They're very finely opposite. It's very hard to decide. If they are man-made and they don't represent reality then looking at reality with a powerful microscope would indicate that they - if - and they don't represent reality it would mean that they'd have to be modified so that they do but then again you're back to the fact that they are man-made in fact. I'm not really certain that those - trying to decide - I don't know whether I can throw cut either of them and say this is definitely wrong.

I: Let's leave it at that point then okay? I realize that that's a very difficult question.

S: I think I reacted hastily.

Question Number Nine

I: Let's go on to question 9 then and you've selected E. Why have you selected E?

S: Well, if you build something and it destroys the environment and you're living in that environment then you're creating adverse conditions to yourself which kind of defeats the purpose. If you're not around to enjoy the electricity then why have the electricity. So if you can - you've first got to examine the effect. Like it'll have a direct - it may have a direct effect on the environment which then has a direct effect on you. So what you build should determine - should be examined to make sure it's not going to be harmful to you otherwise it's going to defeat the purpose of having it. So that's why I'd say that you have to determine the effect before building it.

I: Can science in fact determine the effects of something like an electrical plant on the environment?

S: From what biology I've had there's very - there's food webs and food chains and they're very compli - they can be very complex depending on the situation so trying to trace down every thread of that web could be difficult and you may in fact miss some. So I don't know whether they can determine every possibility - possible effect on the environment. So again it comes back to do we know everything about one topic. We can examine it but again
there may be topics which escape our insight.

I: Should we then base our decision on whether or not to build the plant on a scientific report on how it would affect the environment?

S: I think you'd have to base it on the overwhelming evidence. If it's going to completely blacken the area with scot and smoke or poison the atmosphere these are direct effects and they're adverse to our being. Therefore I'd be in favour of not building it and putting up with the brown outs until an alternative source could be found. I wouldn't want to have to live in that kind of thing just to have light at 5:00 - bright light at 5:00 - and we'd all kind of restrict our use.

**Question Number Ten**

I: Moving on to question 10 then could you explain to me what the problem was with the question for you?

S: I thought - I came down to making sure that scientists don't create monsters in the laboratories and keeping government from interfering, or no, ensuring the controls and effects are enforced. It seems to me that every time that rules are put in somebody breaks them. So you put down the rules and somebody breaks them and they make a monster then you're in trouble. If you - you can't inspect everywhere because there's going to be places that you don't know about or that the government doesn't know about. The government up top. And I don't see like recombinant DNA is a branch of science that is being looked into. It may bring forth benefits to man. I understand, I'm not sure whether this is correct, but they were doing some work in bacteria producing petroleum products and that could have a major effect on people if they could be brought - or on our society - if they could be brought into use. So if you make sure that there's controls then people will - some people will break the controls and you may end up with a monster. So I don't know what's the most important between the two. It seems to be a cause and effect. You can't have people just going around or examining or playing with it helter skelter all over the place because you could end up with...

**Question Number Eleven**

I: And in the final question you chose D and I'd like you to go through each of the four options and explain the reasons for accepting or rejecting them.

S: If new facts are discovered that contradict - that don't quite fit the theory I wouldn't say that you should just scrap the whole works, the whole theory because there may be parts of it that are good. You've got to salvage as much as you can. You don't scrap the whole thing. And just because certain facts don't fit in. You may have to modify so that's the reason I threw out - crossed off or eliminated A from it. All the work put into making the theory shouldn't be scrapped just because certain facts didn't fit in. The theory may be basically sound but it has problems in it that have to be ironed out. You can't change facts because they're observations that are supposed to be objective like we said before and you can't bend what happens to what you think should happen because what you think should happen may not in fact happen. So that was my reason for
throwing out B. You can't say that C because the facts - the fact that something happened is contrary to the theory brings us questions about what's wrong between them. Why don't they quite fit? So you can't keep a theory as it is because there's evidence to say that that is not completely so. Contradictory evidence - you don't want to say this is definitely - those facts have to be wrong when they may have been proved true. That's why I threw out C. If we change the theory a little so it fits the new facts then that helps to encompass everything we know about it so far. More facts come along with it you may have to modify it again. So that was my reason for keeping D. By changing the theory we're not changing any physical laws yet, we're just changing our idea about how certain things happen to encompass another - contradictory evidence to that.

I: Do you think that that happens very often - that they change the theory a little bit?

S: I think so because that - I think - again that's my idea behind the publication of a paper is so that they may have to change their theory. They've examined all facets that they know of yet, right now. Somebody else may bring something else in so that they have to change it a little to encompass the ideas.

I: What about the theories that you're learning in school - are they being changed?

S: Not that I know of yet. The theories - well like most - can you give me an example?

I: Almost anything. The theory of evolution, the theory of gravity.

S: Again it's an ongoing exploration. The theory of evolution - we're coming up with more and more evidence is compiling all the time because more and more people are looking at it so again the theory may have to be changed to encompass this - those new facts that are being brought forth. It's not - a theory doesn't necessarily, when it comes out, hold everything - it doesn't encircle everything, every possible aspect because again we don't know everything about one subject.

I: How about the theory of gravity?

S: We still don't know what actually is gravity. We know that - it's a force but we don't know what causes that force. We know it's - that distance is inversely proportional to the force but we don't know what's behind gravity so the theory of gravity. . . . So, okay there is a theory of gravity but it may have to be modified if we find out something about it. The actual substance of gravity.