Science and Mathematics Education Centre

The Pedagogical Implications of Teacher Personal Philosophies of Science in the School Science Classroom: An Interpretive Study

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ABSTRACT

This thesis addresses the problematic relationship between teacher personal philosophies of science and teacher pedagogy. The research literature on philosophy of science and its impact on science education identifies the persistence and pervasiveness of traditional philosophies of science, such as inductive-empiricism and positivism, that misrepresent the practice of science. Although researchers have expressed concern about the influence of teacher beliefs in inductive-empiricism and positivism on teacher practice in the science classroom, the results of research in this field are inconclusive.

This thesis reports an interpretive research study of three high school science teachers. An interpretive framework was developed in order to assist in the identification of teachers' personal philosophies of science. The framework comprises philosophical theories of ontology, epistemology, and theory building, and the key assumptions of major philosophers of science.

Interpretive analyses were conducted on classroom discourse in order to examine the influence of the three teachers' personal philosophies of science on their teaching practice. Data were collected by means of participant-observation, audio-tape recordings, and teacher and student interviews. The validity of the research was optimised by using triangulation methods.

The results of the thesis in the form of general assertions, indicate that experienced teachers' personal philosophies of science comprise well-established and strongly integrated networks of ontological, epistemological, and theory building beliefs based on the traditional philosophies of science of inductive-empiricism and positivism. The results indicate also that a strong relationship exists between teachers' traditional personal philosophies of science and teacher-centred classroom roles and teaching practices, and that this relationship is reinforced by institutional factors such as curriculum policy and teaching resources, and laboratory design and classroom organisation.
These results have important implications for the implementation of constructivist-oriented curriculum reforms in school science.
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CHAPTER ONE

SCIENCE EDUCATION AND PHILOSOPHY OF SCIENCE

INTRODUCTION

This thesis is presented in five chapters. It reports an interpretive research study that developed an interpretive philosophical framework and analysed classroom discourse for the purpose of (1) identifying teacher personal philosophies of science, and (2) examining their influence on teaching practice and the classroom environment.

This chapter presents an overview of the theoretical and methodological frameworks of the study. The first section explains the problematic relationship between philosophy of science and science education. In particular, this section examines the relationship between developments in philosophy of science and developments in curriculum reform in science education, and examines the influence of philosophy of science on educational innovations such as conceptual change teaching.

Section two describes the research problem, section three presents the purpose of the thesis, and section four lists the research questions that focus the thesis. Section five explains the rationale for adopting an interpretive research approach to the study. Section six presents an overview of the thesis organisation and describes the purpose of Chapters Two to Five.

SCIENCE EDUCATION: THE IMPACT OF PHILOSOPHY OF SCIENCE

Since the 1950s, when Mead and Metraux (1957) investigated science stereotypes, educators have been interested in examining teacher, and more commonly, student views of the nature of science. Before the 1960s, little was written on student and teacher perceptions of the nature of science because science educators, both researchers and teachers, accepted that philosophical theories of inductive-empiricism or positivism described correctly the practice of science and how scientific knowledge
was generated and proved. Inductive-empiricism may be described simply as a belief that experimentation will generate a large number of scientific facts that can be rationalised by the formulation of generalisations. Positivism may be described as a belief in the verifiability of hypotheses by use of observation-based experimentation. Chapter Two discusses these philosophies of science in more detail.

**Teachers' Traditional Philosophies of Science**

Early educational research (Carey & Strauss, 1968; Kimball, 1968; Mackay, 1971; Rubba & Anderson 1978; Schmidt, 1967) used paper-and-pencil instruments to examine teacher and student understandings of the nature of science. Generally, the results showed that teachers and students misunderstood the essence of science and supported traditional philosophies of science such as inductive-empiricism or positivism.

However, both inductive-empiricism and positivism present perspectives "that seriously and dangerously misconstrue the essence of science as a human activity and a philosophical method" (Silverman, 1989, p. 46), and ignore both the application of creative imagination and insight in scientific discovery and the essence of science as a "self-correcting mode of inquiry" (Silverman, 1992, p. 105).

Once the alternative philosophies of Popper, Kuhn, Toulmin, Lakatos, Polanyi, and Feyerabend, which highlight the theory-ladenness of human observation and the tentativeness of scientific knowledge, started to permeate science, science educators became interested in contemporary philosophies of science. They sought to implement the principles of contemporary philosophies of science in curriculum reforms and teacher pedagogy in science education. However, Rowell's (1982) research revealed that contemporary philosophers, such as Kuhn and Popper, have had little influence on traditional conceptions of the nature of science held by university-based scientists and their students.

Robinson (1969) emphasised the need for teachers to be aware of their use of language to ensure that they do not present a false impression of scientific concepts to students. For example, teachers' presentation of gene
or *electron* as a concrete object implies a positivist or inductive-empiricist view of science, rather than indicating the conceptual character of the term.

Recent studies (Koulaidis & Ogborn, 1988, 1989) which have investigated inexperienced teachers' conceptions of the nature of science indicate that, although teachers' conceptions of the nature of science have become more sophisticated, teacher beliefs continue to be influenced strongly by inductive-empiricism and positivism. As recently as 1990, Garrison and Bentley asserted that school science teachers promoted positivist conceptions of science.

In summary, inductive-empiricist and positivist views of the nature of science that have been criticised by educational researchers because they misrepresent the true characteristics of science continue to be very persistent in school science. However, teachers continue to ignore both the existence of science as a self-correcting mode of inquiry and the imagination and insight necessary for scientific discoveries to occur. Instead, many teachers continue to promote inductive-empiricist and positivist notions of the nature of science.

**Contemporary Philosophies of Science in Science Curricula**

The persistence of inductive-empiricist and positivist conceptions of the nature of science has led to attempts by science educators to encourage science teachers to implement, in their teaching, a philosophy of science that is more representative of the nature of science. Science educators, such as Abimbola (1983), Duschl (1990), Garrison and Bentley (1990), and Hodson (1981), have analysed contemporary philosophies of science in order to make them more accessible to teachers.

Abimbola (1983) proposes a 'new' philosophy of science that incorporates common aspects of contemporary philosophers such as Kuhn, Popper, Toulmin, and Feyerabend. Abimbola's new philosophy of science attempts to incorporate the common features of contemporary philosophies of science into a unified philosophy of science. He intends that his new philosophy of science should be used as a superior
alternative to positivism, for the purpose of upgrading science curriculum planning, and that teachers should be introduced to the new philosophy through inservice teacher education programs.

Hodson (1981, 1986, 1988) discusses some of the philosophical misconceptions that science teachers promote in the classroom. According to Hodson (1988), a sound understanding of philosophies of science permits the formulation of goals upon which a valid science curriculum can be based. Martin, Kass and Brouwer (1990) emphasise the epistemological dimension of science and the need for an 'authentic' view of science in the classroom that is based on the diversity of views presented by Kuhn, Popper, Feyerabend, and Polanyi. These researchers developed recommendations aimed at implementing a philosophically effective science curriculum.

However, research by Duschl (1985) on the implementation of new science curricula indicates that curriculum projects continue to be out-of-step with contemporary developments in philosophical thought to the extent that science curricula continue to promote positivist conceptions of the nature of science.

More recently, a number of countries, such as the United Kingdom (Solomon, 1991), the United States of America, and the Netherlands, initiated new national science curricula that were designed to lead teachers to implement philosophy of science issues in science courses (Matthews, 1990). The effects of these curricula on teacher and student conceptions of the nature of science are yet to be fully evaluated. However, in the United Kingdom, Solomon (1991) has found that, although teachers work hard to educate students about the nature of science, students continue to retain views about the truthful, unchanging nature of scientific knowledge that are clearly at odds with contemporary philosophies of science. The results of research studies suggest that contemporary philosophies of science, although promoted by national curricula, have had little impact on teachers' implicit traditional beliefs about the nature of science.
Matthews (1992) argues that, to be effective, curriculum reforms must abandon discrete units of study on the nature of science and incorporate them into general science curricula. According to Matthews (1992), this re-orientation will provide the most positive development for incorporation of philosophy of science studies into science lessons.

In summary, efforts to encourage the introduction into school science of more representative views have been stimulated by science educators' interpretations of contemporary philosophies of science and their recommendations about application of these philosophies to science curricula. School science curriculum reforms which have been designed to facilitate teachers' implementation of nature of science components into their science courses have been introduced in a number of countries. Initial research that assessed the effect of the implementation of the new national school science curriculum in the United Kingdom indicates that belief in inductive-empiricism and positivism persists in school science. Matthews (1992) recommends general incorporation of nature of science units of study into general science curricula as the most effective method of teaching contemporary notions of the nature of science.

**Contemporary Philosophies of Science in Teacher Education**

The combination of a general awareness of the persistence of inductive-empiricism and positivism amongst teacher beliefs and the development of new school science curricula which emphasise nature of science issues has resulted in calls for teacher education programs as mechanisms for altering teacher beliefs about the nature of science.

A number of researchers (Billeh & Hasan, 1975; Martin, 1972; Manuel, 1981; Robinson, 1969; Summers, 1982; Yager & Yager, 1985) argue that increased emphasis on philosophy of science is necessary in both initial teacher education and inservice teacher education programs. These researchers argue that it is important to ensure that teachers have adequate understandings of the nature of science so that they will be confident when teaching students. Akeroyd (1989) argues that, despite curriculum requirements that teachers be aware of philosophies of
science and teach components of the nature of science to students, few
changes occur if teachers are inadequately prepared or supported.

**What Strategies Might Be Adopted?**

For student teachers, units of study could be developed which focus on a
particular philosopher of science and his/her writings in order to
generate a greater appreciation of that philosopher's thoughts, as did
Wandersee (1987) on Francis Bacon. This approach might provide
students with the opportunity to reflect critically on the influences of
various philosophies of science on classroom practice.

Although he accepts the significant influence of the media on the
formulation of public images of science, Gallagher (1991a) continues to
emphasise the important influence of the school, particularly of teachers.
His research focused on the portrayal of science both in resources, such
as textbooks, and by prospective and practicing teachers in the
classroom. The results of his study indicate that, for these teachers,
objectivity is defined by the use of the 'scientific method', and is the
characteristic of scientific knowledge that delineates science from non-
science. Gallagher (1991a) concludes that there is a need for more teacher
education that concentrates on the study of the nature of science.

Another strategy is concerned with teaching about the historical
development of science, either to promote greater teacher awareness of
the essence of science or to provide evidential support for a particular
philosophy of science framework. For example, historical case studies
have been designed to present informed ideas about the nature of science
and scientists (Klopfier & Cooley, 1963). Recently, Akeroyd (1985) and
Gauld (1982) examined particular historical episodes in order to provide
support for a Popperian philosophy of science.

Attempts to determine which philosopher of science provides the most
acceptable explanation of the development of a particular theory in
science have been reported by Hill (1985) and Oldham and Brouwer
developed worksheets on historical incidents for teachers to use in their
science classes. Silverman's resources (1992) focused on public scientific controversies. They are intended to provide teachers with insight into scientific developments that they can share with students.

According to Meichtry (1992), it is important that there are strong connections between the nature of science presented in curriculum materials and the practice and learning of science in the classroom.

In summary, attempts to alter teachers' beliefs about the nature of science have focused on increasing the emphasis on nature of science studies in science teacher education preservice and inservice programs. Recommended strategies include: (1) studying individual philosophers of science and their writings (Wandersee, 1987); and (2) using historical case studies (Akeroyd, 1985; Hill, 1985; Klopfer & Cooley, 1963; Oldham & Brouwer, 1984).

Influence on Teaching Practice of Teachers' Philosophies: Recent Research

Informing teachers about the nature of science seems to have had little impact on teacher beliefs about the nature of science. While developments in curriculum policy and teacher education were occurring in science education, other researchers were focusing on teacher beliefs and the influence of these beliefs on teacher decision making and teacher classroom practice (Clark & Peterson, 1986; Shavelson & Stern, 1981). Science educators also began to examine the influence of teacher beliefs on lesson planning, interactive behavior, the classroom environment, and student beliefs and understandings (Lederman & Zeidler, 1987; Olson, 1981).

This research indicated that, although few teachers think consciously about the nature of science, all teachers have personal philosophies of science which, although they might be subconscious or unarticulated, influence their teaching practice in the science classroom (Brickhouse, 1989, 1990; Gordon, 1984; Silverman, 1989). Zeidler and Lederman (1989) and Gordon (1984) claim that there is an implicit view of science in teacher language. According to Gordon (1984), research indicates that teachers'
'espoused theory' of the nature of science is at odds with their 'theory in use' in the science classroom.

The influence on teaching practice of teacher conceptions of the nature of science was investigated by Zeidler and Lederman (1989) who were concerned that teacher use of everyday language to explain scientific ideas to students promoted naive realism in the science classroom. Using Toulmin's philosophy of science as his framework, Munby (1976) focussed on language use in the context of science, and attempted to describe scientific communication portrayed in textbooks as realist or instrumentalist. His definition of instrumentalism is similar to the definitions of scientific realism and critical realism that are discussed in Chapter Two. This thesis argues, however, that in order to be effective, analyses of language must focus not only on ontological features but also on epistemological and theory building features.

Extending Munby's study, Zeidler and Lederman (1989) analysed teacher discourse and concluded that student conceptions of the nature of science matched the implicit messages on the nature of science that was "embedded in the teacher's language" (Zeidler & Lederman, 1989, p. 777). These studies disclose the importance of teacher language use, and highlight the need for teachers to reflect on the language that they use in the science classroom.

Results from both case studies (Brickhouse, 1989, 1990) and a priori association studies (Lederman & Zeidler, 1987) highlight the influence on teacher practice of teacher beliefs about the nature of science. Brickhouse's (1989, 1990) study indicates also that teachers with greater subject knowledge of science have better appreciation of the essence of science than do teachers with weaker scientific backgrounds who tend to retain inductive-empiricist or positivist views of science. On-going research by Roychoudhury and Roth (1992) is examining the impact of a constructivist classroom on student conceptions of the nature of science.

Research by Duschl and Wright (1989) on teacher decision making models for planning and teaching science shows that both experienced and inexperienced teachers emphasise scientific facts rather than
scientific theory, thereby misrepresenting scientific practice. Another problem confronting the teaching of the nature of science in science classrooms emerged in the same study. Duschl and Wright (1989) obtained results which indicate that if time spent on the study of nature of science issues in science classes is not reflected in assessment, students infer that studies of this kind are not important. These researchers observe also that teaching practice is influenced more by institutional constraints, such as the curriculum, teacher perceptions of student capability, and teacher accountability, than by teacher conceptions of the nature of science.

In summary, there is some uncertainty in the research about the impact on teaching practice of teacher beliefs about the nature of science. Results of recent research do not support conclusively the claims of Robinson (1969) and Martin (1972) about the probable effect of teacher beliefs on instructional approaches. Although Brickhouse (1989,1990) claims that teacher beliefs about the nature of science influence teaching practice, Duschl and Wright (1989) claim that other factors, such as teacher beliefs about students' development, influence teacher decisions about their practice more than do teacher beliefs about the nature of science.

Contemporary Philosophies of Science and Conceptual Construct Teaching

At the time that researchers were starting to investigate teacher beliefs and their effect on teacher decision making, one of the most productive areas of science education research - student conceptual development - was revolutionising researchers' and teachers' conceptions of student learning in science education. Constructivism (Magoon, 1977) is the philosophical theory that underpins this research.

In particular, theories about the conceptual frameworks of individuals sought to explain student conceptual development in science. These theories were informed by the work of Kelly (1955) who developed a theory of personal constructs which, he claimed, were "representations of the universe erected by a living creature and then tested against the reality of that universe" (p. 12) and also by conceptual change theory as
proposed by Posner, Strike, Hewson & Gertzog (1982). As a result of these theories researchers have sought to compare student conceptualisations of phenomena with accepted scientific explanations (Clement, 1982; McCloskey; 1983).

A consequence of this comparison has been the development of pedagogical strategies such as concept conflict (Hewson & Hewson, 1984; Nussbaum & Novick, 1982). Researchers asserted that, because students constructed their own conceptions of science, strategies such as concept conflict would cause students to reassess their conceptions of particular phenomena and alter their concepts to more acceptable science concepts.

According to Confrey (1990), science educators have been supportive of contemporary philosophers of science because the philosophers provided a rationale for work on conceptual construct theory. The writings of contemporary philosophers of science, particularly, Toulmin, Kuhn, and Feyerabend, provided philosophical support for the views of researchers in conceptual construct theory. A number of examples follow, some of which are problematic.

Researchers such as Posner, Strike, Hewson and Gertzog (1982) explained their conceptual construct theory using both Kuhn's paradigms and Lakatos's scientific research programme. However, considering the divergent views held by Kuhn and Lakatos in relation to ontology and epistemology (see Chapter Two), it is difficult to imagine how paradigms and scientific research programmes may be combined without losing the integrity of the philosophies of science proposed by either Kuhn or Lakatos. Stenhouse (1986) also describes conceptual construct theory in terms of Kuhn's philosophy.

Another example is the use by Gilbert and Swift (1985) of Lakatos' philosophy of science to provide support for alternative concept theory which argues that students enter science classes with conceptual frameworks that are alternative to the scientific framework that is being taught in the classroom.
Driver and Erickson (1983) used the theories of Popper to provide a theoretical framework for theories-in-action. However, although Driver and Erickson accepted a tenet of constructivism which asserted that individuals were the constructors of their own conceptual frameworks, they neglected other epistemological features of constructivism such as its existence as a participatory epistemology (see Chapter Two).

Toulmin provided the philosophical framework for Novak's (1980) Epistemological 'V' teaching method which was designed to enable students to relate objects of study in science to their conceptual frameworks.

Initially, conceptual construct theory was applied to specific concepts such as circular motion (Gardiner, 1984), light and buoyancy (Osborne, 1985), motion (McCloskey, 1983), mechanics (Clement, 1982), and electricity (Driver & Easley, 1978). However, as Solomon (1983) discovered, students did not readily give up their beliefs. Her findings are supported by Karmiloff-Smith (1988) who found that students were unwilling to abandon their theories about particular concepts. These studies suggest that greater insight into conceptualisations may be gained by examining the personal philosophies of both students and teachers.

More recently, a number of researchers (Cleminson, 1990; Hawkins & Pea, 1987; Hodson, 1986; Larochelle & Désautels, 1991; Meichtry, 1992) have come to regard conceptual construct theory as providing a method for conceptual change that can be implemented to alter student conceptions of the nature of science so that they more closely reflect contemporary views held by scientists and philosophers of science.

In summary, contemporary philosophies of science have been influential in the development of science education curriculum innovations such as conceptual construct teaching. Many researchers in this field have used philosophy of science to provide a rationale for their theories of conceptual change. Recent researchers recommend the use of conceptual change methodology in order to encourage changes in students' conceptions of the nature of science.
THE RESEARCH PROBLEM

Although contemporary philosophies of science have provided a theoretical basis for innovations in science education such as conceptual change teaching, research indicates that the influence of contemporary philosophies of science has not been extended to teachers' presentations on the nature of science in science classrooms. Much of the research that has focused on examining teachers' understandings of the nature of science highlights the ubiquity amongst teachers' beliefs of traditional philosophies of science such as inductive-empiricism and positivism.

Educators have expressed concern about the negative influence of inductive-empiricist and positivist philosophies on teaching practice and about the images of science that teachers, with these beliefs, evoke in their students. Curricula have been developed which place greater emphasis on teaching nature of science issues in efforts to enable teachers to present to students more representative views of science. Teacher education programs have been recommended in order to educate teachers about nature of science issues. However, current research indicates that teachers continue to hold inductive-empiricist and positivist beliefs about the nature of science.

Research has indicated some uncertainty, however, about the impact on teaching practice of teachers' beliefs about the nature of science. This uncertainty constitutes the research problem of this thesis.

PURPOSE OF THE THESIS

This thesis reports a research study that was designed to:
(1) investigate the personal philosophies of science of three junior high school science teachers; and
(2) examine the impact of the teachers' personal philosophies of science on their teaching practices and classroom environments.

The study involved the development of a model for science education of the relationship between philosophical theories and philosophers of science, and the analysis of teacher and student classroom discourse.
Chapter One

RESEARCH QUESTIONS

The following three main research questions guided the conduct of the study and the development of this thesis.

1. Which philosophical frameworks have had most influence on the development of modern science education, curricula, and pedagogy?
   • What has been the extent of the influence of traditional philosophies of science such as positivism, inductivism, and empiricism?
   • What has been the influence on teachers' beliefs of contemporary philosophers of science such as Popper, Lakatos, Toulmin, Feyerabend, Kuhn, and Polanyi?
   • Is constructivism a philosophy of science and what is the nature of its emerging influence on science education, curricula, and pedagogy?

2. What is the nature of the personal philosophies of science that are held by teachers of school science?
   • How do teacher personal philosophies of science compare with traditional and contemporary philosophical models?

3. How do teacher personal philosophies of science affect teacher pedagogy?

RESEARCH DESIGN: A SYNOPSIS

Most past studies of teacher or student conceptions of the nature of science (Carey & Strauss, 1968; Griffiths, 1991; Kimball, 1968; Lederman & Zeidler, 1987; Rubba & Anderson, 1978; Schmidt, 1967) are based on surveys that comprise philosophical categories into which each teacher or student response is sorted. There are two problems with this research approach. Firstly, because the surveys are based on a priori categories, no new hypotheses emerge. The research only confirms the reliability and validity of a priori categories.

The second problem associated with survey research is the difficulty of sorting all participants' responses into the a priori classifications. For example, Koulaidis and Ogborn (1988, 1989) found that 60 percent of their
respondents could not be classified adequately using the categories which they had developed for their study.

In the study reported in this thesis, these problems were obviated by adopting an interpretive research framework (Erickson, 1986). Interpretive research is based on constructivist epistemology which accepts that observers construct their observations in ways that have meaning for them (Bettencourt, 1992). Interpretive research studies comprise two steps: generation of a priori general categories and, subsequently, generation of a posteriori outcomes in the form of hypotheses or tentative theory.

In this study, a priori categories were generated as a result of the analysis of traditional and contemporary philosophies of science. The categories were used to develop a heuristic model (see Figure 1 in Chapter Two) that provided a framework for subsequent interpretive data collection and analysis. The philosophies of science are described and categorised in the literature review which is presented in Chapter Two of this thesis.

The second part of the study involved the generation of a posteriori outcomes from data that were collected during extensive participant-observation of classroom interactions. Case studies of three different teachers - two experienced and one inexperienced - were conducted at two different high schools in the metropolitan area of a major Australian city. Data collection occurred over a three-month period, and each class was observed for a minimum of eight one-hour lessons. All lessons were audio tape recorded because this method of data collection was the least invasive and produced an accurate record of classroom discourse that was supported by extensive field notes.

The interpretive research approach of this study emphasised the importance of classroom discourse as the mediator between teacher personal philosophies of science and classroom teaching practice. Erickson (1986) argues that this type of research approach allows the monitoring of the immediate meanings of the actions of the participants, so that hypotheses are generated as the meanings emerge. Therefore, the collection and analysis of data allows a posteriori outcomes to emerge and further hypotheses and theory to be developed. This approach to
generating hypotheses has its basis in the grounded theory proposed by Glaser and Strauss (1967).

OVERVIEW OF THE THESIS

Chapter Two, the literature review, presents an analysis of traditional and contemporary philosophies of science based on a comparison of philosophical theories and philosophers of science. This chapter provides the theoretical framework necessary for the interpretive analyses of classroom discourse that are presented in Chapter Four.

Chapter Three explains the rationale of the interpretive research approach for the case studies of three teachers, and describes how the data were collected. This chapter explains also how the teacher-participants became involved in the case studies and the main features of their teaching environments.

Chapter Four presents analyses of classroom discourse of the three teachers involved in the case studies. The analyses used as a referent the philosophical framework developed in Chapter Two, and focused on teacher beliefs at the three levels of ontology, epistemology, and theory building. Three assertions are presented that describe specific features of each teachers’ personal philosophy of science. Appendix A presents the audio-recorded transcript of a one-hour science lesson, and Appendix B presents a copy of the field notes of the same lesson. Appendix C presents a sample transcript of a teacher interview.

Chapter Five focuses on the implications of the analyses described in Chapter Four and, as a result, presents three General Assertions about teachers’ personal philosophies of science and teaching practice. This chapter presents also recommendations for areas of further study that are based on the a posteriori outcomes of the study.

SCOPE OF THE THESIS

This thesis reports on an examination of the personal philosophies of science of three science teachers. In order to achieve this aim in the time
available for the study it was inevitable that the following limitations were placed on the scope of the study.

1. The analysis of philosophical theories was restricted to those associated with ontology, epistemology and theory building that are discussed most commonly by philosophers of science and science educators. The dichotomies and trichotomies that focused on include; idealism and realism; foundationism and non-foundationism; objectivism, constructivism and subjectivism; and absolutism and relativism. Philosophical theories such as existentialism, naturalism, and instrumentalism were not discussed in detail in this thesis.

2. Each of the three teachers involved in the study were observed for a maximum period of three months. It is possible that teachers' personal philosophies of science, as inferred from classroom discourse might vary from science topic to science topic. The interpretive study would be strengthened, therefore, by conducting case studies across as many science topics as possible. However, due to practical constraints it was possible in this study only to observe several topics being taught by each teacher.
CHAPTER TWO

PHILOSOPHY OF SCIENCE:
AN INTERPRETIVE FRAMEWORK FOR SCIENCE EDUCATION

I have no doubt that many professional educators would dearly love a clear, uncomplicated, and definitive description of some univocal 'structure' for each discipline normally involved in the school curriculum. (Schwab, 1971, p.181)

Basically, scientific inquiry is not as neat and clean as science educators often propose. Rather, it is in a continual state of flux in which theories, methods, research questions and so forth compete for supremacy. But this is not to say it is totally devoid of standards or frameworks for judging competing ideas and choosing among them. It merely establishes that a great deal more needs to be taken into consideration and a great deal more ought to be embodied in our science classes. (Duschl, 1990, p. 6)

INTRODUCTION

Describing the features of science which make it a distinctive discipline in a way that is both illuminating and acceptable to peers is a task that has occupied scientists, philosophers, and science educators. Historically, the study of philosophy has been concerned with questions of ontology, epistemology and ethics, but consideration of the notion of science as a discipline has led philosophers of science to concentrate on epistemological issues and on aspects of philosophy that are unique to science, particularly questions of how scientific theories develop and processes of choosing the best scientific theory.

Analysis of the writings of key philosophers of science, particularly of the philosophical assumptions that underpin their theories of epistemology and theory choice, provides a basis for comparison of the variety of philosophies of science considered in this review. The analysis provides a theoretical framework for this thesis, and permits a detailed investigation in Chapters Four and Five, of teachers' personal philosophies from which assertions are derived about the impact of philosophy of science on teaching and learning of school science.
In section one of this chapter, general features are described of a model of philosophical theories that was developed to facilitate comparisons between philosophical theories and key philosophers of science (see Figure 1). Contemporary philosophers of science have developed characteristic philosophies that are dependent on a range of theoretical assumptions such as paradigms, falsification, scientific research programmes, and incommensurability that have led particular philosophies of science to be identified with particular philosophers. For example, reference to the model indicates that Karl Popper presents a Popperean philosophy of science which is based on philosophical assumptions of scientific realism, objectivism, non-foundationism, and absolutism.

However, this somewhat oversimplified one-to-one correspondence between key philosophers and philosophies of science is a contemporary phenomenon that masks the complexities of historical development. Traditional philosophies of science, with input from numbers of philosophers of science, tend to have evolved over time. For example, a major school of philosophy of science called positivism emerged in the late nineteenth and early twentieth centuries. This philosophy is not characterised by an individual philosopher of science, but has been advocated by a number of significant historical and contemporary figures who include Auguste Comte, Bertrand Russell, Moritz Schlick, Rudolf Carnap, Gottlob Frege, Herbert Feigl, Alfred Ayer, and Carl Hempel. This school of philosophy of science is represented in the model in Figure 1 by the philosophers of science Alfred Ayer and Moritz Schlick. For the purposes of this review, only the general characteristics of positivism are discussed in sections two, three, and four of this chapter.

The rationale for placement of key philosophers of science within the model is explained in section two. The rationale is developed from thorough analyses of the writings of key philosophers and an examination of the writings of their supporters and critics. Sections one and two provide, therefore, a basis for comparison of the key philosophers of science.
The key philosophies of science under review in this chapter each possess unique features which explain annotatively, to interested individuals, important developments in scientific thought. These features, which are considered in section three, of this chapter include, *inductivism* for Bacon, *verification* for positivists, *falsificationism* for Popper, *paradigms* for Kuhn, *research programmes* for Lakatos, *conceptual evolution* for Toulmin, and *personal knowledge* for Polanyi.

PHILOSOPHY OF SCIENCE: A MODEL FOR SCIENCE EDUCATION

Figure 1 presents a model for science education of the relationships between philosophical theories and philosophers of science. The model has its genesis in the recent linear models of science educators such as Nussbaum (1989), Giere (1988), and Loving (1991). However, its circular nature permits immediate visualisation of the contrast between philosophers of science and their philosophical views of ontology, epistemology, and theory building. To achieve the same level of comparison with a linear model would require visualisation of four-dimensional space, a task that would be much more difficult for the reader.

Examination of the model in Figure 1 reveals that each concentric circle represents a branch of philosophy. The philosophical branch of epistemology, however, is divided into two levels and, therefore, is represented by two concentric circles. Each circle of the model is intersected by solid or dashed lines. These lines represent borders between philosophical theories within each branch of philosophy. Solid lines, such as the one between Idealism and Naive Realism, indicate that there is no overlap or seepage between neighbouring ontological theories. This structural feature is based on the premise that no individual can be simultaneously an idealist and a naive realist. The dashed lines, such as those between scientific realism and critical realism, show that a philosopher may exhibit features of both theories.
The model reveals that ontology, that is, the branch of philosophy concerned with questions about reality and the existence of phenomena, comprises four ontological theories, each of which proposes a particular notion of reality: idealism, critical realism, scientific realism, and naive realism. The two levels of epistemology, that is, the branch of philosophy concerned with questions about the existence of true knowledge, comprise, firstly, a level composed of two divergent epistemological theories that consider the security of knowledge: foundationism and non-foundationism. The second level comprises three distinct epistemological theories that consider the question of how knowledge about phenomena is generated: subjectivism, objectivism, and constructivism. Figure 1 shows
how epistemological theories are coordinated with ontological theories. Finally, at the centre of the model, is the area of philosophy called theory building which is concerned with the rationale - absolutist or relativist - for constructing scientific theories and explaining the growth of scientific knowledge. Resolving the issue of how scientists select the best scientific theories that purport to provide the best explanations of natural phenomena forms one of the main foci of philosophical discussions about the discipline of science.

The model has been designed to enable ready comparisons to be made between key philosophers of science on the basis of their ontological, epistemological, and theory building underpinnings. The model locates the philosophies of: Francis Bacon, the initiator of the philosophy of science called inductive-empiricism; Moritz Schlick, one of the leaders of the Vienna school of positivism called logical-positivism; Alfred Ayer, a more recent positivist; and contemporary philosophers of science, particularly Karl Popper, Imre Lakatos, Thomas Kuhn, Stephen Toulmin, Michael Polanyi, and Paul Feyerabend. Although there are other contemporary philosophers of science, notably Larry Laudan, philosophers who were selected for this review have had the greatest influence on science education, especially on the reassessment of teaching and learning of science, major curriculum projects, and conceptual change research.

Each philosopher of science is placed in the centre of the model because this shows his relationship with each branch of philosophy and, therefore, shows his particular philosophical orientation as a segment of the pie of philosophical theories. From the model, a table has been generated which lists philosophers' orientations to branches of philosophy (see Table 1). For example, Francis Bacon's philosophy of inductive-empiricism is shown to be absolutist, objectivist, foundationist, and naive realist.

For this thesis, the main advantage of the model in Figure 1 is that it permits positioning of the less well-articulated personal philosophies of science of teachers and students in relation to accepted philosophers of science. The model acts as a heuristic device for rationalising philosophical models in areas of philosophy of science, in particular the areas of ontology, epistemology, and theory building.
Table 1  Theoretical Positions of Key Philosophers of Science

<table>
<thead>
<tr>
<th>Philosopher of Science</th>
<th>Branch of Philosophy</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Ontology</td>
</tr>
<tr>
<td></td>
<td>Knowledge Security</td>
</tr>
<tr>
<td>Francis Bacon</td>
<td>naive realist</td>
</tr>
<tr>
<td>Moritz Schlick</td>
<td>naive realist</td>
</tr>
<tr>
<td>Alfred Ayer</td>
<td>naive realist</td>
</tr>
<tr>
<td>Karl Popper</td>
<td>scientific realist</td>
</tr>
<tr>
<td>Imre Lakatos</td>
<td>scientific realist</td>
</tr>
<tr>
<td>Stephen Toulmin</td>
<td>scientific realist</td>
</tr>
<tr>
<td>Thomas Kuhn</td>
<td>scientific realist</td>
</tr>
<tr>
<td>Michael Polanyi</td>
<td>scientific realist</td>
</tr>
<tr>
<td>Paul Feyerabend</td>
<td>critical realist</td>
</tr>
</tbody>
</table>

As section three of this chapter shows, not all aspects of a philosopher's thoughts on a philosophy of science can be encapsulated in a model such as that in Figure 1; and the same can be said for teacher and student personal philosophies of science. However, in this thesis the model provides an interpretive framework for the analysis of data that were collected from each of the case studies.

The next section examines the placement of key philosophers of science within the model on the basis of analyses of their philosophical writings and the writings of both proponents and opponents of their respective philosophical orientations.

PHILOSOPHICAL THEORIES

Popper (1982) claims that both the audience and the philosopher hold, consciously or unconsciously, "connected theories, views and expectations about the world, and even about the ways in which we learn
to know it," (p. 14). He calls these adopted or typical positions, "isms" (p. 14), and argues that a critical analysis of philosophical positions, in terms of isms, is important for an understanding of the philosophies of science.

More commonly, these isms are known as philosophical theories, and include theories about ontology, epistemology, and theory building. In this section, philosophical theories shown in the model (see Figure 1) are explained in detail and the placement on the model of philosophers of science is justified using both resource material from their writings and resources from their critics and supporters.

**Ontology**

Ontology is concerned with the nature of phenomena and the question of reality. Philosophical theories that consider this question range from *idealism*, which views reality as a mental construct and physical objects as having no existence apart from the mind, to *realism* which accepts that there exists an external reality.

**Idealism**

Idealists assert that we cannot know the external objects that make up our reality without experiencing them and that, therefore, each human's view of reality is constructed in the mind. Berkeley, a more recent idealist (1685 - 1753) and staunch Christian, was committed to the view that, because we cannot know unexperienced physical objects, we are dependant on the intervention of a divine mind. As an ontology, idealism has historical rather than contemporary significance.

**Realism**

By contrast, realism views natural phenomena as having an external reality independent of human thought. Although there are different types of realism, this review considers only the most commonly discussed forms, namely, *naive realism*, *scientific realism*, and *critical realism*. Positivists have been described as non-realist because they consider that questions about reality are immaterial to explanations of the logic of
science (Phillips, 1983). Although consideration of ontology is not important to their philosophy of science (Feigl, 1969), positivist writings reveal an implicit acceptance of the existence of an external reality.

The view that scientific theories describe exactly natural phenomena has been called naive realism by philosophers such as Feyerabend (1975) and Burian (1984), and by science educators such as Hodson (1986) and Selley (1989) who attribute this theory to Francis Bacon's ontology. A cornerstone of Bacon's philosophy is the claim that we can directly observe nature, although this is possible only if we purge our minds and senses of influences and prejudices that prevent us from seeing reality (Rossi, 1974). Bacon argues further that facts can be obtained only from the reality of nature:

Man, being the servant and interpreter of Nature, can do and understand so much and so much only as he has observed in fact or in thought in the course of nature: beyond this, he neither knows anything nor can do anything. (Bacon in Spedding et al., 1968, p. 47)

The second form of realism to be considered is scientific realism. According to scientific realists, although there does not exist a truth correspondence between scientific theories and reality, theories attempt to describe reality truthfully and, as scientific theories become more sophisticated, they describe reality more closely. Scientific realists believe that, although a theory can be used to describe reality, without the theory, reality continues to exist. They assert that it is not true to claim that in the absence of a theory the world would not be the way it is (Urmson & Rée, 1989).

Rescher (1987) argues that scientific realists believe that theoretical entities of natural science exist actually as science theorising characterises them. However, this description seems to correspond more closely to naive realism. Rescher uses the term approximationism to describe the belief that, although theoretical entities envisioned by natural science do not exist actually in the way that current science claims, science does have "the general right idea" (p. xii). The notion of approximationism seems to be more congruent with the scientific realism of Urmson and Rée (1989).
According to Hacking (1988), there are two types of scientific realism. The soft version defines scientific theories as true or false on the basis of whether they allow study of further phenomena, whereas the hard version asserts that whether theories are true or false depends on whether they correspond to the world, or to facts about the world. While Hacking's soft scientific realism seems to correspond to the scientific realism of Urmson and Rée (1989), his hard scientific realism seems to be congruent with naive realism. Evidence from the contemporary philosophers considered in this study reveals that most are scientific realists who accept the existence of an external reality. However, an examination of the relationship between scientific theories and reality reveals differences in their positions.

Examination of Popper's philosophy of science indicates that he is a scientific realist:

The issue raised here is that of metaphysical realism, in a form which does not so much stress the existence of physical bodies as the existence of laws. For physical bodies are only an aspect of the law like structure of the world which alone guarantees their (relative) permanence.

(Popper, 1982, p. 80)

What we attempt in science is to describe (and as far as possible) explain reality.

(Popper, 1979, p. 40)

Although Lakatos (1970) largely supports Popper's view of realism, he is more concerned with describing how scientific theories are generated and maintained through scientific research programmes.

Toulmin (1972), also, is a scientific realist. He describes scientific theories as an agglomeration of concepts, and it is in his discussion of conceptual reorganisation that he considers the existence of reality. He asserts that conceptual reorganisation of scientific understanding requires the development of explanations for relevant aspects of Nature and recognition of the limitations of those explanations as being representative of nature. Toulmin's (1953) metaphor of theories as maps further supports the view that he is a scientific realist for whom the landscape is reality and
maps are representations of the landscape in the same way that theories are representations of reality.

According to Polanyi (1959, 1962, 1967a, 1967b), the search for reality is the essence of science. Scientists search continually for hidden reality and, as a consequence, make important scientific discoveries. This assertion reveals that Polanyi is a scientific realist. A view that is further supported by Polanyi's claim that:

[S]cientific tradition derives its capacity for self-renewal from its belief in the presence of a hidden reality, of which current science is one aspect, while other aspects of it are to be revealed by future discoveries.  
(Polanyi, 1967b, p. 82)

A scientific realist perspective also is displayed by Kuhn's (1977) consideration of the development of scientific theories. He explains that, with the passage of time, theories become more articulated and "in the process they are matched to nature at an increasing number of points and with increasing precision" (p. 289).

By contrast with other forms of realism, critical realism asserts that, because there are no completely objective sense data and because most basic perception involves interpretation of an already accepted theory, it is logically untenable to separate fact from theory (Selley, 1989). There is a continuum of knowledge which extends from common sense based on personal experience to abstract propositions based on a chain of argument (p. 89). Feyerabend's (1962) claim that "our theories determine . . . our conception of reality" (p. 40) displays an acceptance of the critical realist position because it denotes a construction of a reality rather than the search for an external reality. Sociologists of science (Barnes & Edge, 1982; Collins, 1982, 1985) share this claim. When discussing the nature of reality, Barnes and Edge (1982) write:

No body of knowledge, nor any part of one, can capture, or at least be known to capture, the basic pattern or structure inherent in some aspect of the natural world.  
(Barnes & Edge, 1982, p. 4)
Phillips' claim (1983) that positivists are non-realist is based on the difficulties that confronted positivists when they sought to apply the verifiability principle to scientific theories. Because scientific theories search for phenomena that cannot be verified strictly by observation positivists are forced to confront the question of whether theoretical entities can be regarded as real entities if they cannot be verified. For positivists, it is the connections between observations of the real world and theories which are most important (Giere, 1988). Polanyi (1959) is very critical of positivists who try to deny the existence of reality. For him, the search for reality forms the basis of science.

However, without the real world it is not possible to make the observations that permit the connections between observations and theories. Statements from Feigl (1969) and Ayer (1973), both of whom are positivists, reveal their acceptance of an external reality and indicate acceptance of naive realism. Feigl (1969) talks of "knowable things in themselves" (p. 14), and Ayer (1973) describes sense impressions as providing a bridge between perceptions and reality.

Although ontology addresses questions about the nature of phenomena, it raises other questions about how we learn about phenomena and apply the understandings that we develop. Philosophical theories developed to answer these questions belong to epistemology which is the study of knowledge generation and justification.

Epistemology

Knowledge can be described as true, justified belief (Lewis, 1970), and philosophical theories about knowledge, particularly its structure, development, and its communication between people, belong to epistemology or the study of knowledge. The study of epistemology can be divided into two major levels. The first level requires deliberations on whether knowledge can be proven. Foundationism and non-foundationism are the epistemological theories which provide opposing explanations in this area. The second level addresses the question of how knowledge is generated, or how it develops. Epistemological theories of
objectivism, subjectivism, and constructivism provide different answers to this question.

**Foundationism and Non-foundationism**

Historically, Western philosophers can be described as *rationalists* or *empiricists*. Rationalists believe that substantial knowledge about the world can be achieved by reason alone. Although rationalists accept the use of senses to describe features such as redness, they maintain that reason and logic are the main routes to knowledge development (Urmson & Rée, 1989). Rationalists include philosophers such as Descartes, Spinoza and Kant. By contrast, empiricists believe that all knowledge is derived from experience, and that understanding of the world is gained through sense impressions which are communicated by theory-free observation. Bacon was a staunch supporter of the empirical approach; and required that minds be *unclouded* by theories when making observations of the world (Farrington, 1973). Positivists also emphasise the importance of empiricism, and maintain that there is a need for theory-free observations. They claim that it is possible to verify or falsify an observation empirically by using bodily senses or instruments which extend the senses (Hesse, 1969).

According to both rationalists and empiricists, knowledge is based on fundamental understandings that are secure. Descartes required that the starting point for investigations be that which is *absolutely indubitable* (Popper, 1979, p. 35). The belief that knowledge is based on facts and can be proven is called *foundationism*. Both rationalists and empiricists are foundationists.

Contemporary philosophers of science who are discussed in this review incorporate aspects of both rationalism and empiricism in their discussions of how scientific knowledge develops and is justified. However, contemporary philosophies disagree with both empiricism and rationalism when the status of knowledge is considered. Popper, Lakatos, Kuhn, Toulmin, Polanyi, and Feyerabend assert that knowledge cannot be secure and, consequently, their interest focuses on theory development in
science. These philosophers belong to the counterposition of non-foundationism that is described by Lakatos:

For centuries knowledge meant proven knowledge - proven either by the power of the intellect or by the evidence of the senses. Wisdom and intellectual integrity demanded that one must desist from unproven utterances and minimise, even in thought, the gap between speculation and established knowledge. . . . Einstein's results . . . turned the tables and now very few philosophers or scientists still think that scientific knowledge is, or can be, proven knowledge. (Lakatos, 1970, pp. 91-92)

Both foundationists and non-foundationists are interested in the relationship between ideas and reality. Consideration of this relationship has led to the formulation of philosophical theories known as objectivism, subjectivism, and constructivism. These theories seek to explain the position of justified, true knowledge.

**Objectivism**

Objectivists believe that true knowledge exists out there, externally of the individual or knower. Objectivist views assert that phenomena and knowledge of phenomena exist independently of the mind. There are truths which are independent of human wishes and beliefs, or there are independent ways of establishing absolute truths or answering particular questions (Lacey, 1976). Bacon was an objectivist who believed that scientific knowledge is external to the knower, that it can be 'discovered', and that the way to discover the knowledge is by theory-free observation. According to Hesse (1969), Bacon believed that there were hidden entities whose function and existence could be revealed only by observation, or by inference of cause via observable effects. Bacon wrote:

I am building in the human understanding a true model of the world, such as it is in fact not such as a man's own reason would have it be.

(Bacon in Spedding et al., 1968, p. 110)

Positivists maintain Bacon's objectivist view by supporting the existence of knowable things-in-themselves (Feigl, 1969, p. 14). They believe that
genuine knowledge can be communicated only by propositions that "consist of one-to-one correspondence of words (names, predicates) of a sentence to objects or properties or relations denoted by these words" (Feigl, 1969, p. 13). Positivism is objectivist because it contends that knowledge can be found in statements or words which exist independently of the human mind.

Popper's objectivism is based on his assertion that knowledge exists in the form of the "logical content of theories, conjectures and guesses" (Popper, 1979, p. 73) which is published in books, found in libraries, and is present in discussion of theories. He divides the world into three sub-worlds. World one is the material world of physical objects; world two is the subjective world of mental states; and world three is the objective world of scientific ideas, and includes libraries, film, books:

Almost every book is like this: it contains objective knowledge, true or false, useful or useless; and whether anybody ever reads it and really grasps its contents is almost accidental. (Popper, 1979, p. 115)

Popper's claim that knowledge can exist as an independant 'body' indicates his support for an objectivist conception of the status of knowledge. Lakatos' support for objectivist views is clear. He claims that his concept of research programmes belongs to a third world of Kuhn's paradigm theory:

[T]he - rationally reconstructed - growth of science takes place essentially in the world of ideas, in Plato's and Popper's 'third world', in the world of articulated knowledge which is independent of knowing subjects. (Lakatos, 1970, p. 179-180)

This quotation highlights Lakatos acceptance of Popper's concept of objectivism. Lakatos maintains that one cannot understand the growth of scientific knowledge without reference to the independence of knowledge from its creator or discoverer.

Subjectivism

Subjectivists may subscribe to either an idealist or critical realist ontology and, at the same time, accept that knowledge about natural phenomena
exists only in the mind of the knower (Lacey, 1976). The view that knowledge exists only in the mind of the knower is the essence of subjectivism, and is expressed by proposals that knowledge does not exist in books, and that the knower must develop knowledge for themselves (Chiari, 1973).

According to Suppe (1977, p. 638), Feyerabend’s subjectivist philosophy contends that there is no connection between truth and observation statements and that, consequently, one is required to accept statements as the observer interprets them. These observer interpretations may be either true or false but it is not possible to determine experientially the truth or falsity of observation statements and, therefore, it is logically invalid to search for correspondence with the 'real' world. Suppe's analysis is supported by Feyerabend (1962) who argues that there is no such thing as objective knowledge in the Popperian sense:

Our theories determine . . . our conception of reality.

(Feyerabend, 1962, p. 40)

Constructivism

In recent times, the philosophical theory of constructivism has come into prominence in the fields of science and science education. Constructivism is a multi-faceted philosophical theory and extends from subjectivist to objectivist perspectives. This epistemological theory views knowledge as constructed by cognising beings. When individuals interact with objects, events, or phenomena in the world they construct their own image of reality which fits external reality but which is not necessarily a match. Knowledge forms part of this reality construction but it cannot be said to be the truth, especially if truth is regarded as correspondence with reality. This has led a philosopher of science, Ernst von Glasersfeld (1992), to propose that a mental construction can be called knowledge if it is viable, that is, if it works:

Constructivism holds that we can know only what our minds construct, but that its constructing is not free . . . some of our conceptual constructs and theories work and others do not. For constructivists, the fact that something works (is viable) does not mean that it therefore is a
representation of that 'real' world that prevents other things from working. (von Glasersfeld, 1992, p. 2)

The search for viability is one of the features of constructivism that has led constructivists to assert that the theory goes beyond subjectivism. The other feature of constructivism that distinguishes it from both subjectivism and objectivism is its assertion that theories can be constructed only within a particular culture. Theories are constructed by using the language and concepts of a culture and by utilising interactions between members of a culture. This feature has led some researchers to call constructivism participatory epistemology:

The successor to objectivism is not subjectivism, by way of negation, but rather the full appreciation of participation, which is a move beyond either of them. . . . It is by no means easy to adopt this participatory epistemology. Years of efforts directed at demonstrating a correspondence between 'knowledge' and an ontological reality are deeply ingrained in our language and have been foisted on us from the moment we were born. . . . Traditionally we are supposed to play the role of discoverers who, through their cognitive efforts, come to comprehend the structure of the 'real' world.

(Varela in Mahoney, 1989, p. 141)

Kuhn is a philosopher of science with strong ties to constructivism. He views science as an endeavour carried out by communities of scientists, and is critical of objectivist perspectives. Kuhn (1970) contends that knowledge is constructed by communities of scientists, and particular criteria such as fruitfulness and accuracy are used by scientists to determine the acceptability of knowledge:

We are all deeply accustomed to seeing science as the one enterprise that draws constantly nearer to some goal set by nature in advance. But need there be any such goal? Can we not account for science's existence and its success in terms of evolution from the community's state of knowledge at any given time? Does it really help to imagine that there is some one full, objective, true account of nature and the proper measure of scientific achievement is the extent to which it brings us closer to that ultimate goal? (Kuhn, 1970, p. 171)
For Kuhn, knowledge is embedded in shared examples that evolve within a scientific community as members of the community interact. This knowledge is not subjective because it is time-tested, systematic, and corrigible (Kuhn, 1970).

Toulmin displays support for constructivist epistemology when he asserts that, in the third world of objective knowledge promoted by Popper and Lakatos, the emphasis should not be solely on the intellectual content but should include appraisal of the practice of members of the science discipline within an historical context. It is the interaction between members of a discipline which leads to the construction of knowledge. Toulmin’s view is that objective scientific knowledge should be considered within the framework of the particular historical era, because it is not possible to divorce knowledge from its historical context (Toulmin, 1976).

Polanyi believes strongly that the knower constructs her or his own knowledge, and his views in this area mark him as a supporter of constructivism. His main treatise is presented in his book Personal Knowledge (1962), the title of which reveals his acceptance of the view that individuals internally construct knowledge.

The participation of the knower in shaping his [sic] knowledge which had hitherto been tolerated only as a flaw - a shortcoming to be eliminated from perfect knowledge - is now recognised as the true guide and master of our cognitive powers. (Polanyi, 1959, p. 26)

Polanyi is quick to assure readers that acceptance of the shaping of knowledge by individuals is not a slide into anarchy but is a responsible act (1967b). The viability of this knowledge is determined by the search for reality (Polanyi, 1967b) and it is this search for viability which indicates that Polanyi is more of a constructivist than a subjectivist. He seems to be very much a constructivist when he asserts that the understanding gap between the teacher and the taught can be bridged only by intelligent effort on the learner’s part to make sense of the teacher’s statements and that learners construct knowledge from their own personal experience (1967b).
This description of the features of constructivism highlight that although differing perspectives of constructivism exist they share a basic commonality of the search for truth based on the application of viability.

Although epistemological theories of objectivism, subjectivism and constructivism might not be described explicitly in reports on scientific research they often can be inferred. What is described, usually in greater detail in scientific reports, is the process used by researchers to justify the acceptance of findings as true knowledge. This process is called theory building and is dependent on epistemological assumptions. Philosophies of science have attempted to provide a systematic explanation of how theory building is conducted in science. These explanations are based on either (1) the existence of a single approach for selecting the best scientific theory, which is called absolutism, or (2) rational decision-making processes within a community of scientists, which is called relativism. Most contemporary philosophers of science use historical examples to support their conceptions of how theory building occurs.

Theory Building

For contemporary philosophers of science such as Kuhn and Toulmin, the question of how scientific theories emerge is the focus of their explanations of how science develops. However, for traditional philosophers, particularly inductive-empiricists such as Bacon, their focus is less on theory and more on the collection of empirical data. In order to consider the options involved in developing scientific theory it is necessary to understand what the term theory means in scientific explanation. According to Giere (1988), a theory is not a well-defined quantity in science, and examination of descriptions from various philosophers and philosophies of science indicates that there is no univocal description of the term.

The philosophers and philosophies of science under consideration in this review either (1) propose how the use of a recommended method in science can lead to the best scientific theory, or (2) describe how the history of scientific development indicates the approaches used by scientists to construct, in actuality, the best scientific theory.
Chapter Two

According to Popper (1980) and Kuhn (1970), a new theory is accepted because it incorporates all the material covered by the theory that it displaces, solves problems the previous theory could not solve, and has greater predictive power than the previous theory.

Absolutism and Relativism

The opposing philosophical theories that explain how a scientific theory is constructed are called absolutism and relativism. It seems to be easier to describe absolutism than relativism. Theorists who claim that there is only a single method for deciding if one scientific theory is better than others are called absolutists. Absolutist philosophies constitute prescriptions of how science should be conducted. By contrast, those who theorise that outside agents influence the change from one theory to another are called relativists. The difficulty with relativism is that philosophers who support this theory often are accused by their critics of being non-rational (Newton-Smith, 1981) and of causing theory building to succumb to the vacissitudes of 'mob rule' (Lakatos, 1970). Consequently, relativists often explain in detail why their relativism is rational (Kuhn, 1970).

Absolutism

Absolutist theories take two major forms. The first is based on the inductive-empiricist and positivist view that:

- **Theory A is true and solves all the problems it is supposed to solve.**

This view represents a form of absolutism which is supported by both inductive-empiricists and positivists who argue that theories can be proven. Both accept that the tenets of inductivism provide the correct method for investigating phenomena and, as a consequence, theories are verified by the verification of hypotheses (Charlesworth, 1982; Phillips, 1983).

According to Bacon (1968), who was an early inductive-empiricist, theories are "general axioms" which are developed from "particulars" collected using the senses (p. 50). Before a general axiom can be proposed,
however, it is necessary to collect many particulars. This idea forms the basis of inductivism that is characterised by the need to amass a body of facts about an aspect of nature by using theory-free observation and experimentation. Once the facts or data have been collected, it is possible to induce a generalisation if, after searching for agreement and disagreement within the data, no disagreeing data have been found. Kuhn (1977) claims that, for inductive-empiricists, experimentation is far more important than theories and that experiments are carried out not because they are necessary for the extension of a theory, but to see how nature behaves under previously unobserved and often non-existent conditions.

Positivists view theories as "conceptual tools" which are used to organise "primary facts" (Ayer, 1976, p. 110). Therefore, theories tend to be equated with hypotheses, which cannot be true or false, but they are useful for predicting facts that are reports of sense experiences (Phillips, 1983). Positivists who are interested in the logical construction of scientific theories from observations often are referred to as logical-positivists. They are not interested in accounting for the origin and development of theories. As a result, their construction of a theory is based on empirical see page from observational data as propositions to formal concepts and postulates (Feigl, 1969).

Van Fraassen (1980) provides a contemporary description of a theory in terms of positivism which highlights the importance that positivists place

![A THEORY]

This match is most important for science

Aspects of the real world Observational Terms (O)

Logical connections provide meaning for Theoretical Terms (T)

Figure 2 A Positivist explanation of theories
on the relationship between observational data and postulates, or theoretical terms. Figure 2 is a diagrammatic representation of Van Frassen's description. According to him, a theory is made up of observation and theory statements, or terms. The observation terms are expressed as propositions and the theoretical terms as postulates. For the proposal of a coherent theory, it is necessary that the connections between the propositions and postulates be logical.

The second form of Absolutist theory is based on Popper's (1974, 1979, 1980) view that:

- **Theory A is better than theory B because it approximates the truth (we believe) and there has been no evidence that it is not true.**

Popper (1974, 1979) proposed a method of scientific investigation involving conjectures and falsification. All theories and laws are bold conjectures which can be true or false but it is expected that the conjectures will be mainly true. Empirical knowledge is used to attempt to falsify the theories or laws against objective knowledge. If this attempt is unsuccessful then theories or laws are accepted because they have a greater truth content than their predecessor (Popper, 1979, p. 81).

Popper describes theories as universal statements, or as nets which are cast to catch the world. The aim of scientists is to make the mesh in the net finer (Popper, 1980, p. 59) Although theories are conjectural, they pervade all experimentation and influence both empirical facts and laws which reside inside the cocoon of the theory. Statements from the theory and a particular empirical fact, which is a singular event, can be combined to permit a hypothesis to be deduced. Hypotheses have predictive power (Popper, 1979, 1980).

Lakatos (1970) is more interested in the methodology of research programmes which he describes as a series of theories rather than individual theories. According to McMullin (1976), scientists use the term theory in the sense that it is something which develops over time while logical-positivists, inductive-empiricists, Poppereans, and Lakatosians view theories as logical entities that are independent of historical and
developmental aspects. Lakatos' description of a research program most clearly reflects the scientists' definition of a theory (McMullin, 1976).

Falsification, as a method for removing theories, is supported by Lakatos (1970) who adds, however, that before falsification can take place there must be an alternative theory available to replace the falsified theory. He claims that "no experiment, experimental report, observation statement or well-corroborated low-level falsifying hypothesis alone can lead to falsification" (p. 119). Lakatos argues that scientists do not give up their theories on the basis of a single critical experiment that shows their theory to be incorrect. They are more likely either to reject the findings of the experiment or to modify the theory in order to accommodate the findings of the experiment.

Relativism

Relativist theories take three main forms. The first is based on the views of Kuhn (1970) and Polanyi (1962) that:

- There is no method to explain the selection of one theory in preference to another. The development of a theory can be explained only after the event.

Kuhn (1977) is critical of absolutist theories when he argues that theory building requires "disagreement between rational men [sic]" but that "such a disagreement would be barred by a shared algorithm" (p. 332). By contrast, absolutist positions remove scientific judgement from theory building. However, under the system proposed by Kuhn, scientists can be asked to explain and defend their construction and acceptance of a scientific theory. Scientists belonging to a group specialisation use features such as accuracy, agreement of deductions with existing experiments, consistency, scope, simplicity, and fruitfulness, when constructing and selecting scientific theories (Kuhn, 1977, pp. 321-322). The selection of a particular theory by experts is not an irrational activity (Kuhn, 1977, p. 336).

For Kuhn (1977), it is important that when people examine theories they do not lose sight of the historical perspective. Laws are empirical, and are
developed from observation or experiment. When first developed laws supply information that is lacking and, as science develops, they are refined but never disappear. Theories are not based directly on empirical laws but the law-like statements in theories are a combination of empirical laws and personal perception.

Like Toulmin (1953), Polanyi (1962) uses a map metaphor to explain his conception of a scientific theory: "[A]ll theory may be regarded as a kind of map extended over space and time" (p. 4). Like a map, a scientific theory is made up of a set of rules for guiding people through a region of scientific endeavour and, like a map, a scientific theory relies on knowledge such that if the map or theory is followed but the expected outcomes are not reached, then the premises of the theory need to be reconsidered. But a theory, like a map, is such that a scientist's bias is not able to alter the findings which arise through use of a theory (Polanyi, 1962).

For Polanyi, the focus of his philosophy of science is scientific discovery which reveals hidden reality. He believes that other philosophers of science have been remiss because of the lack of emphasis on scientific discovery in their writings (Polanyi, 1962). He is critical of the emphasis placed by some philosophers of science on the verification of scientific theories (Polanyi, 1959). In particular, he is critical of inductive-empiricists and positivists who emphasise a single method as the correct way of assessing the validity of a discovery. According to Polanyi, "discovery depends on personal commitment which cannot be objectified" (Polanyi, 1967b, p. 25). Polanyi is critical also of Popper's theory of falsificationism that requires scientists to seek disconfirming evidence for their theories. He describes it as "not only contrary to experience, but logically inconceivable" (1967b, p. 78-79).

Instead, for Polanyi (1946), theory building is based on the intuition and conscience of scientists working within a scientific community and cannot be derived by following a particular method.

The second form of Relativist theory is based on Toulmin's (1970,1972) view that:
• **Theories are historical, logically independent entities which evolve over time.**

Although the collection of facts is an individual activity, a consideration of the impact of facts on theories and the selection of one theory instead of another involves communal interaction between professionals which occurs by means of discussion, journal articles, and conferences. Professionals base their decisions on the scope, applicability and preciseness of the theory (Toulmin, 1972). There can be a multiplicity of theories within a field of phenomena, but more advanced theories provide more complex information at greater depth. Older theories continue to provide useful information, but the language of each theory is incommensurable, a factor about which users of theories need to be aware (Toulmin, 1953, p. 103).

According to Toulmin (1970), to explain how science develops it is necessary to investigate empirically the actual development and growth of science. Each theory contains a family or system of concepts. Toulmin (1972) is interested in examining the role of concepts in the growth and expression of knowledge which can be achieved only by bringing together philosophical analysis of concepts and study of conceptual evolution of theories via historical and scientific discoveries.

The third form of Relativist theory is based on Feyerabend's (1975) view that:

• **When constructing scientific theories anything goes.**

According to Feyerabend (1975), falsificationism is an attempt to force order on a chaotic and irrational human enterprise called science that "is likely to hinder science" (p. 179). He claims that all absolutist theories are simplistic because they require the comparison of one acceptable theory against a class of facts within a domain so that only one acceptable theory can exist within a domain at one time. He asserts that it is more realistic to maintain that a domain consists of a plethora of "partly overlapping, factually adequate but mutually inconsistent theories" (Feyerabend, 1975,
p. 39). In terms of scientific investigation anything goes (Feyerabend, 1975, p. 28).

Feyerabend (1975) describes a theory as a combination of ill-defined objects such as laws, experimental results, prejudices, and observations which exist in a particular historical framework: "No single theory ever agrees with all the known facts in its domain" (p. 52). The language of each theory which is used to explain observations is unique to that theory and changes when a new theory emerges (Feyerabend, 1962). Scientific theories are a way of looking at the world and, when a theory is accepted, it "affects our general beliefs and expectations, and thereby also our conception of reality" (Feyerabend, 1962, p. 29). His thesis has led Feyerabend to argue that features of reality are a human invention that are designed to bring order to our surroundings.

PHILOSOPHIES OF SCIENCE AND THEIR UNIQUE FEATURES

Although sections one and two of this chapter provide an analysis of philosophies of science and attempt to clarify their respective positions with respect to philosophical theories of ontology, epistemology and theory building, the unique features of each philosophy under consideration in this review have not yet been examined. The purpose of this section is to examine, in some detail, the unique features of the philosophies of science under consideration in this review.

Bacon and Inductive-Empiricism

The philosophies of science of inductive-empiricists and positivists propose a method for the practice of science. Bacon wanted to replace speculation based on reasoning with empirical investigations. His views were endorsed by famous experimental natural philosophers such as Boyle, Hooke, and Huygens who, although they realised the shortcomings of Bacon's theories, applauded him for providing a liberating philosophy based on experimentation (Hooykaas, 1987). The emphasis on experimentation also led to the development of scientific instrumentation which enabled more detailed and more accurate examination of natural phenomena (Rossi, 1974).
Bacon's method of scientific discovery can be separated into two parts. Firstly, he promoted observation and experimentation for the purpose of gaining data or facts about the natural world. Secondly, he developed the theory of inductivism to explain how true knowledge can be built up from observations. Although inductivism has been found to be logically unsound (Wisdom, 1987; Popper, 1980), because it claims that generalisations which can be applied to an infinite number of situations can be induced from a finite number of observations, it continues to influence science education (Charlesworth, 1982; Wisdom, 1987).

Positivism

Positivism retains both inductivism and empiricism. However, instead of seeking to build up scientific facts and to provide a method for discovery of scientific truths, as did Bacon, it seeks to explain how scientific knowledge can be justified (Passmore, 1983). Knowledge is truth if it is justified by empirical observation and by the analytical, logical connections between observation and theory. Thus, scientific knowledge consists of (1) solid facts that must be observable or measurable (Phillips, 1983), and (2) conclusions that can be inferred from these facts.

The requirements of both inductive-empiricists and positivists for theory-free observations has been criticised as not being a true representation of the way that science is practised. Hanson (1959) is most critical of this requirement. He claims that "there is more to seeing than meets the eyeball" (p. 7). Instead of seeking to purge their minds before carrying out observations, researchers must be aware that they operate within a theoretical framework that influences the observations that they make. Einstein (1938) realised that personal theories influence both what scientists observe and the types of experiments that they conduct. The language used to describe observation has theoretical considerations already built into it. For example, the use of the term dissolving as a description for the disappearance of a solid in a liquid carries with it theoretical implications (Hodson, 1986).

Although Hanson (1969) writes that "there are no logical-positivists around today" (p. 84) their legacy of the need for theory-free observations,
verification, and reductionistic analyticalism continue to influence the presentation of science practice in science education (Cawthorn & Rowell, 1978; Benson, 1989).

Karl Popper

Popper's (1980) critique of logical-positivism, particularly inductivism and theory-free observations, led him to propose conjectures and refutations as the scientific method for expanding scientific knowledge. Bold conjectures are tested empirically, not in order to prove the conjecture but to attempt to falsify it (Popper, 1980). Popper realised that scientists tend to be unwilling to give up their theories in the face of emergent falsifying evidence. Instead, they are likely either to modify the theory or attempt to falsify the evidence. From Popper's perspective, theories that cannot not be falsified progress towards the truth (Popper, 1982).

Loving (1991) describes Popper as the scientists' philosopher. His influence on scientists' perceptions of the nature of science is extensive and is attested to by scientists such as Medawar (1967) and Gregory (1980).

Imre Lakatos

Lakatos (1970) adopted Popper's philosophy of science as a starting point for the development of his philosophy of scientific research programmes. His argument is based on the assertion that, in each scientific research programme there, exists a hard core of accepted propositions that are irrefutable. Outside of the hard core there exists a belt of soft core assertions that are open to empirical testing. Positive empirical results indicate to scientists in the research programme that they are working in the right direction.

Scientific progress is achieved by competing research programmes that can be progressive or degenerative. Progressive research programmes are considered by Lakatos to be better than others because they have greater predictive power and their extra predictions are able to be empirically confirmed (Worrall, 1976). The difficulty with this view of scientific
progress is that, because comparison of research programmes is possible only in hindsight, there can be no rational grounds for choosing one research programme over another (Hill, 1985). Feyerabend (1976) writes of Lakatos' philosophy that "it is surprising to see that a philosophy which makes such a fuss about rationality and objectivity should possess so abjectly little of either" (p. 135).

**Thomas Kuhn**

The essence of Kuhn's philosophy is associated with his focus on the expressions: paradigms, normal science, revolutionary science, and incommensurability. Kuhn is associated strongly with paradigms and revolutions. Indeed, the expression paradigm permeates many human endeavours which are far removed from science (Gutting, 1980). The wide applicability of this term and the readability of his works have made Kuhn a well-known philosopher.

For Kuhn (1970), the term paradigm has two basic meanings. In the first, a paradigm is a conceptual framework with which to view the world, and comprises theories, techniques, beliefs, and background information shared by the members of a given community (p. 175). The second meaning is "one sort of element in that constellation; the concrete puzzle solutions which, employed as models or examples, can replace explicit

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**Figure 3**  Kuhn's model of scientific progress
rules as a basis for the solution of the remaining puzzles of normal science" (p. 175). The need for specific definitions of the concept of paradigm arose because, in his earlier edition of The structure of scientific revolutions (Kuhn, 1962), the meaning of paradigm varied from situation to situation (Masterman 1970). According to Kuhn (1970), a paradigm constrains not the subject matter, but the activities of a group of practitioners within a disciplinary matrix who have shared commitments to beliefs and models.

From a Kuhnian perspective, the progress of science is represented by Figure 3. Progress from Paradigm 1 to Paradigm 2 can occur only if a second paradigm is available. However, according to Watkins (1970), who is a critic of Kuhn, Kuhn's view of the scientific community is that of "a closed society, intermittently shaken by collective nervous breakdowns followed by restored mental unison" (p. 26).

Kuhn's view of the nature of science has tended to polarise opinion to the extent that either he is venerated or pilloried by other writers in the field of philosophy of science. Aspects of his philosophy which generate the most criticism are the rationality of paradigm choice, the occurrence of periods of normal science and revolutionary science, and incommensurability between paradigms (Burian, 1984; Lakatos, 1970; Siegel, 1985; Suppe, 1976; Toulmin, 1972; Watkins, 1970). However, in his efforts to answer the questions raised by his critics, he has been censured by Suppe (1976) who claims that Kuhn "has given up much of what was most distinctive, original and exciting about his position" (p. 637).

Whatever the inconsistencies of his philosophy, its impact on philosophers, scientists, social scientists, and science educators has been extensive, particularly his concept of paradigms and his emphasis on the social aspects of decision making. According to Fennel and Liveritte (1979), Kuhn describes the practice of science as it actually happens. Giere (1988) describes The structure of scientific revolutions as "the most influential book on the nature of science to be published in the twentieth century" (p. 32).
Stephen Toulmin

Toulmin's (1972) philosophy of science may be described as conceptual evolution, the progress of this evolution is influenced by internal and external features. Internal features are composed of selection criteria that are used by members of a scientific discipline to appraise conceptual innovations. External features are the opportunities that are provided within a society for doing original scientific research. According to Toulmin's philosophy, science evolves in small steps which involve conceptual change. Because a collection of concepts make up a theory, scientific theories are constantly undergoing evolution and change as their constituent concepts change.

By examining the historical development of science it is possible to formulate generalisations about the actual practice of scientists, both individually and collectively, as professional groups (Toulmin, 1970). Toulmin (1976) is critical of Lakatos and Popper who seek an understanding of science from only the words of scientists. An understanding of science requires also a study of scientists' practice in order to provide insight into which practices are most fruitful for the testing of currently accepted theories.

Michael Polanyi

Polanyi's philosophy of science is based on two basic premises. Science is characterised, firstly, by the search for a hidden reality and, secondly, as a consequence of this search, by personal participation of the knower in all acts of understanding so that contact with the hidden reality can be established. Polanyi called this personal participation in knowledge development personal knowledge. He is strongly critical of any form of totalitarianism where one group in the community seeks to control the activities of the larger group (1959, 1967b). This political view influences his philosophy of science and helps to explain his criticism of absolutist philosophical theories.

For Polanyi, science is made up of two inseparable components: discovery and verification. Polanyi is concerned that other philosophers of science
neglect the discovery component of science because it cannot be defined
by a particular scientific method (1962). According to Polanyi (1967b), for
scientific discoveries to take place a scientist must have both a thorough
background in the subject - tacit knowledge - and intuition. Tacit
knowledge is the ability to envisage the relationships between parts of
phenomenon and to recognise the whole from the parts (1967b). All
individuals have this facility but in some it is more highly developed than
in others.

Polanyi's emphasis on discovery is supported by the scientist Root-
 Bernstein (1988) who is concerned about the simplistic representations of
scientific discoveries in school textbooks and popular literature. For Root-
 Bernstein, Polanyi depicts accurately the qualities that a scientist must
have to make scientific breakthroughs. Although Polanyi began his
professional career as a physical chemist, his philosophy, in particular his
conceptions of personal knowledge and tacit knowledge, has influenced
curriculum development in areas such as art and music education
(Bowman, 1982; Sibbald, 1988) rather than science education.

Paul Feyerabend

Feyerabend, who is called the infant terrible (Suppe, 1976) of philosophical
debate on the nature of science, has caused other philosophers to evaluate
their views on the practice of science. He is most concerned that science
does not become another ideology, although he believes that it already
has done so (Feyerabend, 1984). Feyerabend's view is that examination of
science and the history of science shows that there is no single correct
method of doing science, and that researchers use both rational and
irrational approaches to support their scientific theories (Feyerabend,
1975). Accordingly, the best scientists are those with open minds that
enable them not to fall for the first ideological street singer they meet
because they have studied science as an historical phenomenon along
with other ideologies (Feyerabend, 1975).

SUMMARY

This examination of key philosophers and philosophies of science reveals
the complexity of scientific endeavour and the difficulty of explaining the
features of science that make it unique. It is argued that Bacon and
positivist philosophers prescribe a single scientific method that is based on induction and that provides a recipe for doing science. Although Popper supports the view that science is based on a particular method, he requires deduction and falsification, rather than induction and proof, in order to obtain the best scientific theories. Lakatos expanded Popper's philosophy and introduced the concept of research programmes as a mechanism for explaining how scientific knowledge develops. Kuhn, Toulmin, and Feyerabend assert that it is not possible or logical to restrict science to a particular method, and that a study of the history of science provides insights into how science develops.

The possibility of discovering scientific knowledge which is proven no longer seems to be a viable option for scientists, if ever it was. The term discovering implies that knowledge exists out there to be found. Proven implies that once scientists accept something as knowledge it has an exact correspondence with reality. This review has argued that, in contemporary philosophies, there is no support for proven knowledge and that the concept of discovery is open to question.

A feature of the development of scientific knowledge that has been emphasised by Kuhn and Toulmin is the significant role which sociological and psychological features play in the scientific decision-making process. Kuhn's emphasis on sociological and psychological aspects led Lakatos to accuse him of allowing mob rule to be the determiner of successful scientific theories. Others claim that Kuhn has got it right and that the scientific community is the locus of rational authority of science (Gutting, 1980). The latter perspective maintains that science comprises social and cognitive aspects.

The model for science education of philosophical theories and philosophers of science presented in section one of this review provides an interpretive framework for analysing teachers' and students' personal philosophies of science. In Chapter Four the personal philosophies of science of three high school science teachers are examined and compared with the traditional and contemporary philosophies of science that are described in this review.
Chapter Two

This chapter describes how both contemporary and traditional philosophies of science seek to provide coherent explanations of how scientific knowledge is generated and how it evolves. Scientists have recognised the important contribution that philosophy of science makes to defining the unique features of science as a discipline.

According to contemporary philosophies of science, because scientific knowledge is generated creatively by scientists it is changing all the time and, therefore, can never be a proven fact. Also, because scientific knowledge is generated by scientists it can never be known whether scientific knowledge corresponds to reality. Like inductive-empiricism and positivism, these contemporary philosophies accept the importance of observation and experimentation for the evolution of scientific knowledge but, unlike inductive-empiricism and positivism, they assert that observation and experimentation are defined by underlying theory. Kuhn, Toulmin, and Feyerabend present the view that the scientific community, rather than a particular scientific method, determines what is acceptable scientific knowledge.

There is clear agreement in the science education literature on the need for teachers to be cognisant of philosophy of science in order for them to teach science effectively. A teacher's personal philosophy of science might influence not only the material they present to students but also their actual teaching practice. As discussed in Chapter One, a mechanism for collecting the data necessary for investigating teachers' personal philosophies of science is presented in the next chapter.
CHAPTER THREE

THE RESEARCH APPROACH

INTRODUCTION

Chapters One and Two address the first research question: Which philosophical frameworks have had most influence on the development of modern science education, curricula, and pedagogy? The purpose of Chapter Three is to discuss the research approach that was used to obtain answers to the remaining research questions of the study: What is the nature of the personal philosophies of science which are held by teachers of school science? How do teacher personal philosophies of science affect teaching practice and the quality of the classroom learning environment?

The research literature reviewed in this chapter indicates that it is possible to identify teachers' views of the nature of science by analysing their classroom discourse. In this study, elucidation of teachers' implicit beliefs about the nature of science is based on analyses of teachers' classroom discourse and interview transcripts. Research suggests that the philosophy of science to which explicit support is given is not necessarily reflected in teachers' practice, and that teachers' implicit philosophical beliefs might vary from their explicit avowals (Edmonson, 1989; Gordon, 1984). The study examined the influence on teaching practice and the classroom environment of teachers' personal philosophies of science.

This chapter is divided into five major sections. Section one explains what is meant by the term science classroom discourse analysis in the context of this study. In this section, metaphor is introduced as a heuristic device which provides insight into implicit beliefs of teachers about the nature of science. The origins of metaphor from linguistics and world view theory are outlined.

The second section provides the rationale for the application to the study of an interpretive research approach. This approach is based on a constructivist epistemology and was selected as the most appropriate method for obtaining answers to the research questions. An overview of
Chapter Three

the characteristics of the research design, particularly the interpretive framework and interpretation of classroom discourse, is presented also in this section.

In section three, the data sources of this study are described, particularly the participating schools, teachers, and students. Section four describes the methods used to collect data. Features of the rigor of the research design, including reliability and validity, are defined and the value of their application to this interpretive research study is considered. Finally, ethical issues of data collection are examined, including the problematic issue of candour in research.

The fifth section addresses the question of data analysis in interpretive research. Two approaches are described which are used in this study to reduce the data from lengthy transcripts to smaller, more manageable vignettes containing references to the nature of science. These vignettes form the basis for the interpretive analyses of data that are presented in Chapter Four.

SCIENCE CLASSROOM DISCOURSE ANALYSIS

For the purposes of this study, classroom discourse consists of the language interaction between teacher and student in the course of a science lesson. To ensure that an accurate transcription of classroom discourse could be made after the completion of each science lesson, all lessons were recorded using an audiotape recording machine. However, the researcher realised that, in order to give full meaning to the classroom discourse data, it was necessary to consider the context of the science lesson, that is, the key features of the classroom environment that constitute the framework of classroom discourse. Data which describe the context of the science lesson were recorded in the form of field notes. These data were used to give meaning to the science classroom discourse data.

Discussing the context of the science lessons is important because it enables meaning to be attributed to the interactions which occur in the classroom, and can be used to justify the assertions which are based upon
analysis of science classroom discourse. As Mischler (1979) argues, without context, action and language have no meaning. Solomon (1987) is supportive of classroom interaction studies as a non-invasive way of exploring student meanings. The collection of data in this study was achieved with minimal disruption to the school, science, and classroom programs by using discourse analysis of science classroom talk as the major research focus of the study.

Metaphors

For the purpose of this study, metaphor is not only a figure of speech but is a "pervasive, indispensable structure of human understanding by means of which we figuratively comprehend our world" (Johnson, 1987, p. xx). Linguistics and world view theory are two areas of study which can be used to ascribe meaning to metaphors that are used in science education. Both areas can inform interpretive research assertions that are based on metaphorical analysis of classroom discourse data.

Language

Since Aristotle's time, metaphors have been recognised as an important aspect of language and literature. Positivists, with their emphasis on unchanging observation language, regard metaphors as a frivolous use of language and as not appropriate for use in scientific language (Ortony, 1979). However, Black (1962) raised the profile of metaphors when he declared that metaphors were important aspects of language because metaphors permit us to perceive aspects of reality that they also help to construct.

According to Ortony (1975), metaphors, analogies, and similes are closely related and are characterised by expressions of the form X is Y. Muscari (1988) describes analogies and similes as subsets of metaphor. Duit (1991) identifies metaphors and analogies as knowledge that is mapped from one domain to another such that a system of relations which apply to one domain also apply to the other. For example, if the xylem of a plant's transport system (Domain 2) is described as the drinking straws (Domain 1)
of the plant then it might be inferred that the plant sucks liquid up the xylem just as a person sucks liquid up a drinking straw (Relation).

According to various researchers (Ortony, 1975; Provenzo, McCloskey, Kottkamp & Cohn, 1989; Schön, 1979; Searle, 1979), metaphor cannot be separated from the context in which it is used because the meaning of a metaphor arises from that context. Metaphors are used to evoke new mental images in listeners or to provide linguistic short-cuts in conversations. However, metaphors also can be unduly constraining, especially when they lead to a singular view of a situation, an aspect of metaphor use which Schön (1979) describes as cognitive myopia and Aspin (1984) describes as thought stoppers. Examples are expressions such as education for citizenship and diet as a nutritionist's nightmare. These are some of the aspects of metaphor which can be sought in classroom discourse data.

The significance of language in providing information on conceptions gained momentum with the publication of the work of Lakoff and Johnson (1980) who propose that "most of our conceptual system is metaphorical in nature" (p. 4), a position that is supported by Arbib and Hesse (1986). In their book, The Metaphors We Live By, Lakoff and Johnson (1980) analyse metaphors which people use in everyday situations and reveal the ubiquity of metaphors in language. In particular, they highlight the work of Reddy (1979) on the conduit metaphor. Reddy asserted that this metaphor, or metaphorical schema, pervades English language communication and promotes a positivist-objectivist epistemology because it implies that language is a carrier of knowledge and that knowledge can be transferred or conveyed from one individual to another. The conduit metaphor underpins expressions such as transfer ideas, store ideas, convey ideas, or ideas flowing out or escaping. Reddy (1979) provides an alternative approach to language called the toolmakers paradigm in which language expressions imply construction or comprehension of ideas, rather than conveyance of ideas.

World View Theory

According to Holton (1984), metaphor has played a constructive role in clarifying scientific theories. This use of metaphor in science and science
education is related to both the linguistic view of metaphor, as described by Duit (1991), Lakoff and Johnson (1980), Ortony (1975, 1979), Reddy (1979) and Schön (1979), and world view theory (Kilbourn, 1980-1981; Proper, Wideen & Ivany, 1988; Cobern, in press). According to Jones (1972), an individual's world view is the set of beliefs which influences not only their observable behaviour but also their thoughts and feelings.

<table>
<thead>
<tr>
<th>World View</th>
<th>Root Metaphor</th>
<th>Reality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animism</td>
<td>Man</td>
<td>All natural phenomena have a will similar to that of man.</td>
</tr>
<tr>
<td>Mysticism</td>
<td>Love</td>
<td>The level of reality is determined by the intensity of love.</td>
</tr>
<tr>
<td>Formism</td>
<td>Similarity</td>
<td>All natural phenomena follow natural laws. Both exist.</td>
</tr>
<tr>
<td>Mechanism</td>
<td>Machine</td>
<td>All natural phenomena can be explained by interactions between real, discrete particles.</td>
</tr>
<tr>
<td>Organicism</td>
<td>Integration</td>
<td>The organic whole contains the absolute truth. Fragments can be built up to a coherent totality.</td>
</tr>
<tr>
<td>Contextualism</td>
<td>The historic event or the active present</td>
<td>Reality exists but perceptions of it depend on the context.</td>
</tr>
</tbody>
</table>

The methods used by Pepper (1970) and Roberts (1970) to classify world views are based on the underlying root metaphor which defines the features of world view. For example, Pepper (1970) describes mechanism as a world view for which the concept of the machine is the root metaphor. A mechanistic world view leads to the claim that natural phenomena can be explained in terms of the interactions between the discrete parts which make up the whole (Kilbourn, 1980-1981). Mechanism describes the workings of the world in terms of the workings of machinery such as clocks, spacecraft and engines.

Kilbourn (1980-1981) uses Pepper's classificatory system (see Table 2) of world views and root metaphors to examine the philosophical orientation of science curriculum materials, and argues that the classificatory system
can be applied equally to individuals. World view theory can be applied to the work of Hawkins (1983) who claims that some of the metaphors used by teachers are likely to have little or no meaning to students if the language used has no reference to student experiences. For example, teacher's talk of heat flowing may be meaningless to the class if the only features of heat that students have experienced is its ability to warm items or cook things.

Metaphors used by teachers and students in science classes can be a mixture of linguistic metaphors, of the form 'X is Y', and root metaphors from world view theory. Therefore, teacher and student use of metaphors in the science classroom can be used to infer both the world view of an individual and their personal philosophy of science. Both linguistics and world view theory conceptions of metaphor have value when the meanings of metaphors used by teachers and students are assessed. In the analysis of classroom discourse, in Chapter Four, which aims to identify teachers' personal philosophies of science, both analytical conceptions form part of the interpretive framework.

RESEARCH DESIGN

The use of classroom discourse data to examine the research questions of this thesis required a specific method of investigation. Generally, educational research studies lie on a continuum that ranges from interpretive to normative (Cohen & Manion, 1989). In this study, the categories presented in Chapter Two (see Figure 1) were developed in order to provide a framework for interpretive data collection and analysis.

These a priori categories constitute the normative component of the study. The interpretive component gave rise to a posteriori categories about the relationship between teachers' philosophies of science and their classroom teaching practices. These a posteriori categories were embodied in assertions that are presented in Chapter Four and Five of this thesis.

Normative research is characterised by an objectivist epistemology and is an inappropriate research approach for this study because, in the search for meaning in classroom interactions, the research approach requires
study of metaphor used in classroom discourse. However, objectivists refuse to accept the cognitive value of metaphors or the significance of meaning which underlies metaphors (Cohen, 1978). The need to use metaphorical analysis as a major source of data for this research constrains the structure of the study, and indicates that an objectivist-based research approach is inappropriate.

Objectivism requires also an external reality so that observations can be made without observer influence. Working from within a normative, objectivist framework involves a methodology where researchers have usually little contact with the subjects of the research. Clearly, such an approach would have been inappropriate for this study where the researcher performed the role of an interpreter of the use of language in the science classroom:

[I]t is impossible for us to ever stand outside [reality] and take the stance of an observer with perfect knowledge. . . . What is possible is . . . knowledge which includes the awareness that it is from a particular point of view. (Lakoff, 1987, p. 261)

Instead, a constructivist epistemology provided a more appropriate rationale for the research methodology. Constructivists maintain that individuals are knowing beings who construct their own knowledge, and who have control over their knowledge (von Glaserfeld, 1984). Constructivists believe that an observer constructs her observations in a way which has meaning for her, and that her observations are subjective rather than objective (Bettencourt, in press). However, construction of knowledge is possible only within a culture which relies on negotiated meanings by means of language and the truth of these observations for constructivists depends on their viability. Within language are metaphors which help individuals to construct meanings in ways that have significance for them (Johnson, 1987). As a consequence, constructivists view metaphors as significant and valued components of language. Analysis of language which is obtained by observing classroom interactions belongs to interpretive research methodology and is congruent with a constructivist epistemology (Erickson, 1986; Gallagher, 1991b).
Chapter Three

According to Jacob (1989), the benefit of interpretive research is that it can broaden the perspective of researchers when they are examining a problem by emphasising the need for starting the research with an orientating theory rather than with a specific hypothesis. Interpretive research does not place over-reliance on statistical probability which, according to Walberg (1984), has plagued the normative approach to investigations on science education issues.

The Research Study

The interpretive research design of the study comprised two components: (1) the construction of an interpretive framework, and (2) an empirical (Phillips, 1983) investigation of science classroom discourse.

Construction of an Interpretive Framework

An extensive literature review was conducted in order to answer the first research question which asked about the influence of philosophical frameworks on the development of modern science education, curricula and pedagogy. The review analyses traditional and contemporary philosophies of science, and provides a theoretical framework for the subsequent analysis of teachers' personal philosophies of science (Erickson, 1986). See Chapter Two for a presentation of the literature review.

Interpretation of Classroom Discourse

The second step in the research study was participant observation of classroom interactions. This approach enabled the researcher to collect classroom discourse data by means of audio recordings and extensive field notes. The concurrence of these data collection activities ensured that the language and context of the classroom would be correlated. This was combined with teacher input from interviews and discussions in order to search for insight into teacher personal philosophies of science. Erickson (1986) claims that this type of research approach allows the researcher to monitor the context of the actions of those involved, that is, the actors. It permits also a research focus on the content of classroom interactions,
which is essential for an analysis of propositions and metaphors contained in the language of teachers and students. In particular, the research focused on meaning-perspectives which often are held outside the conscious awareness of those who hold them (Erickson, 1986).

As a participant-observer, the interpretive researcher must expect the unexpected and rely on intuition when collecting and analysing data because, as Clark and Westrum (1987) have noted:

What is expected is looked for.
What is looked for is seen.
What is unexpected is unobserved.
What is unexpected is unreported. (Clark and Westrum, 1987, p. 3)

The collection of interpretive data allows categories and further hypotheses to be developed. This approach to generating hypotheses has its basis in grounded theory, as proposed by Glaser and Strauss (1967). The final outcome of data collection and analysis is generation of theory, proposal of categories, and presentation of hypotheses. A useful feature of the grounded theory approach is that it provides definitive information on the sample size of the data which enables the researcher to determine when no further data needs to be collected:

Once the data being found by the researcher no longer provides new information to develop properties of a category, the category is said to be saturated. (Spector, 1984, p. 462)

DATA SOURCES

In this study, data were collected from two government high schools which are situated in a large Australian city. Both schools follow curriculum guidelines prescribed by the State’s Ministry of Education. The guidelines are divided into a general set, which defines curriculum policy in the school, and specific sets, which define subject disciplines. In 1987, the State abandoned its continuous three-year science program and adopted a science curriculum for Years 8 to 10 that is based on discrete science topics or units. The specific guidelines are published in the officially approved
State Science Handbook as *topic objectives*, and provide descriptions of the discrete topics. At the time of the study, science departments in both schools used the officially approved handbook as the framework of their science programs.

**The Schools**

The schools were selected on the basis of teacher interest in the study and their proximity to the university from which the study was conducted. Lakatos High (a pseudonym) is one of the largest high schools in the State and is situated in a middle-to-upper-middle class area. It prides itself on maintaining good community relations and has a waiting list of students wishing to attend. Science class sizes in Years 8 to 10 ranged from 27 to 32 students. Two teachers, Mr Frank Marks and Mr Peter Cash (both pseudonyms), volunteered to be involved in the segment of the study being conducted at Lakatos High.

Bacon High (a pseudonym) is a much older school and was the second school involved in the study. Bacon High has a smaller student population and, because of its special programs, such as the fencing and arts programs, attracts students from both metropolitan and country areas. At Bacon High, Mr Greg Spenser (a pseudonym) volunteered to be involved in the program after the researcher spoke to the science staff at a meeting. Women teachers at both schools did not volunteer to be involved in the study. Lakatos High had a very small proportion of women on its science teaching staff and Bacon High science staff seemed to find the topic of the study to be too esoteric.

**The Classes**

In consultation with the teachers involved in the study, it was agreed that data would be collected from junior science classes. This decision was based, firstly, on the fact that all of the teachers involved in the study taught a junior science class. The second significant factor was that, at junior science level, a wide range of science topics is presented to students. This variety provided an opportunity for the search for metaphors in teacher and student language across a relatively wide range of science
Chapter Three

topics. One of the advantages of this study was its independence from the science discipline orientation of participants. For the purposes of the study, Frank's Year 8 science class, Peter's Year 9 science class and Greg's Year 10 science class were selected for observation (see Table 3).

The Participants

Frank and Greg were very experienced teachers. Each had taught for at least 20 years. Frank's area of expertise was biology. Greg had experience in teaching a wide range of science subjects at various levels but, at the time of the study, was concentrating on teaching physics to junior and senior students. By contrast, Peter had less than two year's teaching experience. He expressed a lack of confidence in his scientific knowledge but indicated that he felt more confident about his teaching knowledge. His areas of specialisation were biology and human biology. Because of his administrative responsibilities, Frank taught approximately 0.8 of a normal teaching load. Peter taught 0.6 of a normal teaching load because he was working to complete a Bachelor of Education degree. Greg taught a normal teaching load of five science classes per day.

Table 3 Participant Involvement in Observations

<table>
<thead>
<tr>
<th>School</th>
<th>Teacher</th>
<th>Class</th>
<th>Observation Time (hours)</th>
<th>Interview Time (hours)</th>
<th>Topics Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lakatos</td>
<td>Mr Cash (Peter)</td>
<td>Year 9</td>
<td>10</td>
<td>1.5</td>
<td>Energy in the Home</td>
</tr>
<tr>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Me and My Environment</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>This Chemical World</td>
</tr>
<tr>
<td>Lakatos</td>
<td>Mr Marks (Frank)</td>
<td>Year 8</td>
<td>11</td>
<td>0.8</td>
<td>Transition Science</td>
</tr>
<tr>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Animals and Plants</td>
</tr>
<tr>
<td>Bacon</td>
<td>Mr Spenser (Greg)</td>
<td>Year 10</td>
<td>8</td>
<td>0.75</td>
<td>Physical Sciences - Force; Energy; Work; Pressure in Liquids; Buoyancy</td>
</tr>
<tr>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Science Topics

During the study, Frank's Year 8 class studied the topics of (1) Transition Science, which focused on matter and physical and chemical changes, and
Chapter Three

(2) Animals and Plants, which focused on classification and evolution. Peter’s Year 9 class studied (1) Energy in the Home, which required a study of static and current electricity, (2) Me and My Environment, which required a study of ecology and human health, and (3) This Chemical World, which required a study of atomic structure and chemical reactions. Greg’s Year 10 class was involved in a physical sciences unit of study which examined topics that focused on concepts of force, energy, work, pressure, and buoyancy (see Table 3).

DATA COLLECTION

The classroom data were collected during a three month period in the first and second school terms of 1992. Methods of data collection included: (1) audio and video tape recordings of a total of 29 hours of classroom discourse, (2) field notes of a total of 29 hours of observations of science lessons by the researcher as participant-observer, and (3) audio tape recordings of approximately 3 hours of teacher interviews (see Table 3). Concurrent data collection and analysis helped to ensure that the quantity of data collected was sufficient but not excessive (Sowden & Keesves, 1988). This approach revealed also any areas where more data needed to be collected.

Audio and Video Tapes

Both audio and video recordings were analysed to present verbatim transcripts of the whole-class discourse of both students and teachers during science lessons (see Appendix A for a sample of an audio transcript). However, when students worked in groups it was not possible to record all verbal interactions. Therefore, the researcher selected particular groups of students for more detailed observation during these lesson activities.

Field notes

Audio recordings of science lessons were correlated with field notes made by the participant-observer. Field notes were especially useful because they helped record important aspects of teachers’ use of resources such as overhead transparencies (OHPs), textbooks, whiteboards and blackboards,
Chapter Three

video recordings, and practical demonstrations (see Appendix B for a sample of field notes). All teachers in the study used a range of teaching resources although their frequency of use varied. For example, Peter used OHPs more than did the other teachers, and Greg tended to make greater use of blackboard, video, and practical demonstration than did either Frank or Peter.

Interviews

Important data for analysing teachers' personal philosophies of science were collected also from interviews with teachers and students. For students, the interviews were informal and were conducted during class time when they were working either in small groups or individually in order to complete practical activities or worksheets. Teacher interviews took place when teachers were free of lesson responsibilities. The interviews were conducted once the classroom observations were finished so that some of the initial analysis of the data could be discussed with the participant teachers. The interviews were semi-structured, that is, they were based on a list of questions that were designed to explore teachers' beliefs about the nature of science (see Table 4). However, the relationship between the interview schedule and and the exact order and form of the questions used during the teacher interviews was very flexible (see Appendix C for a sample of a teacher interview). The results of the interviews were compared with the findings of discourse analysis. As for

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Interview Schedule for Teachers' Interviews</th>
</tr>
</thead>
<tbody>
<tr>
<td>What are the features of science which differentiate it from other subjects?</td>
<td></td>
</tr>
<tr>
<td>What is your view of how scientific ideas develop?</td>
<td></td>
</tr>
<tr>
<td>Explain how you think that students learn new ideas in science.</td>
<td></td>
</tr>
<tr>
<td>What do you think is the best way to teach science?</td>
<td></td>
</tr>
<tr>
<td>What is the students' role in the science classroom?</td>
<td></td>
</tr>
<tr>
<td>What is your role in the science classroom?</td>
<td></td>
</tr>
</tbody>
</table>
classroom discourse, all interviews were audio tape recorded and transcribed.

Classroom Observations

A single class of each of the three teachers was observed for between eight and eleven hours (see Table 3). Prior to data collection, it was assumed that some teachers' views about the nature of science might emerge readily and be clearly identifiable within a small number of lessons but that others might take longer. Because one of the major aims of this research was to use classroom discourse analysis, in particular analysis of metaphor, to examine teacher personal philosophies of science, it was important that sufficient data were obtained from each class to enable the elucidation of personal philosophies. During some lessons, student discourse was recorded by leaving the recorder operating with a group of students.

As participant-observer, I was present in each class and participated in the lessons. Students often approached me with questions about the activities that they were doing in their science class. At the same time, I recorded field notes, ensured that the lessons were audio tape recorded, and interviewed students.

Reliability, Validity and Generalizability

The validity of an experiment may be categorised as internal and external validity. An experiment has internal validity if the experimental treatment can be shown to be responsible for the results observed during the treatment. Reliability is a statistical concept that may be described as the expectation that the same results will be achieved if the same experimental procedure is followed by other researchers. An experiment has external validity if results can be generalised to a different population or setting. Therefore, external validity is the same as generalizability (Cohen & Manion, 1989).

However, by contrast with normative researchers, radical constructivist researchers such as Marshall (1990) and Bettencourt (1991), maintain that interpretive research should address goodness criteria, rather than
reliability or validity criteria. Marshall (1990) describes reliability and validity as positivistic terms which do not have a place in the constructivist lexicon. However, other interpretive researchers such as Benson (1989), Erickson (1986), and Merriam (1988), discuss reliability and validity of interpretive research approaches in ways that differ from their use in normative research. Some of the difficulties of applying these criteria to interpretive studies and some of the solutions used in this study are presented in the following sections.

Internal Validity

In interpretive research, the researcher has the responsibility of observing phenomena and then interpreting the data which emerge from the observations. For a research approach to have internal validity the interpretations should represent adequately the participants’ reality constructions (Merriam, 1988). In this study, the purpose of the researcher was to explain the participants' conceptions of the nature of science using data obtained from observation of classroom discourse and interviews. The internal validity of the researcher's interpretations of her observations of teachers' and students' discourse in both the classroom and interviews was optimised by using three major interpretive research strategies.

Firstly, observations were conducted continually over a period of time in the natural settings of the science classrooms (Merriam, 1988). This approach to observation helps obviate any biases that may exist. For example, teachers and students have the opportunity to become familiar with the researchers presence in the classroom so that her presence has less influence on their behaviour. This approach also provides sufficient observation time to permit the salient characteristics of teachers' personal beliefs to be identified.

Secondly, the teachers were provided with opportunities to negate or support the researcher's preliminary interpretations of her observations (Benson, 1989; Erickson, 1986). Ball (1988) calls this approach to internal validity respondent validation. These interpretations generated further theory which suggested other areas of investigation.
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Thirdly, *triangulation* was used to optimise the internal validity of the study. The value of triangulation is that it allows investigators to be more confident that the evidence which they have obtained has been rigorously collected and can be used to make meaningful inferences from which theory can be generated (Mathison, 1988). Triangulation may be described as "the application and combination of several research methodologies in the study of the same phenomena" (Denzin, 1988, p. 511). Mathison (1988) claims that "multiple methods and sources of data" (p. 13), called *triangulation*, are essential to ensuring that a study has the research validity necessary to make it an acceptable research report.

In particular, *data triangulation* was achieved by collecting data from a number of different science classes. This approach ensured that it was possible to make inferences about teachers' personal philosophies of science in different classroom settings. *Within-method triangulation* involved using different ways of collecting data, such as classroom observations and interviews, within the interpretive research framework. This approach allowed the researcher to check the interpretations obtained from classroom observations against the interpretations generated from interviews. *Theory triangulation*, based on different philosophical perspectives of the nature of science, was used to interpret teachers' personal philosophies from the data collected during the observations and was designed to support assertions made about teachers' conceptions of the nature of science. However, *investigator triangulation* was not possible because the data were collected by a single investigator.

**Reliability**

According to Merriam (1988), the application of reliability criteria to interpretive research is problematic because human behaviour is never static. As Tesch (1990) notes, in interpretive research "no two scholars produce the same result even if they are faced with exactly the same task" (p. 304). The concept of reliability assumes the existence of a single reality which, if studied repeatedly, will produce the same results. However, according to constructivists, we cannot know reality with any certainty and, therefore, each individual creates her or his own version of reality (Lincoln & Guba, 1987). Interpretive research seeks to examine multiple
versions of reality. Thus, the search for a reliability which requires a single reality seems a questionable proposition in interpretive research.

Guba and Lincoln (1988) propose the use of the term *dependability* instead of reliability which, they suggest, can be achieved by carrying out a *dependability audit* on the research approach. This approach entails presenting the research in enough detail for an independent observer to be able to attest that 'good practice' has taken place in the conduct of the research. This criterion was addressed in order to optimise the reliability of the study.

**Generalizability**

For interpretive researchers, application of the normative criterion of external validity, or generalizability, to their study is questionable because, in interpretive research, generalizability requires formulation of statements about populations from the study of a single case or a small number of cases (Merriam, 1988; Wilson, 1979). Producing generalizations of this type is not the aim of interpretive research. Instead, interpretive research aims to describe the environment in which the study is set and the conceptions of the participants in sufficient detail to cause readers of the report to identify with the participants and to consider how the findings, assertions and theories which emerge from the study can be applied to other similar situations. Lincoln and Guba (1987) call this approach to generalizability, *transferability*. Erickson (1986) asserts:

> [T]he responsibility for judgements about logical generalization resides with the reader rather than with the researcher. (Erickson, 1986, p. 153)

In this interpretive study, transferability was optimised by: (1) working with a number of participants, (2) presenting a detailed description of all aspects of the study, and (3) presenting this thesis in language that is accessible to the expected audience.

The study was designed to investigate three teachers' beliefs about the nature of science in relation to a model (see Figure 1 in Chapter Two) that permits comparisons to be made with the views of key philosophers of science. The study's transferability is associated, therefore, with the
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prospects of the model being applied by other researchers and the expectation that science educators who read published papers based on this thesis will reassess their approaches to the teaching of the nature of science.

Firestone (1990) claims that one of the purpose of interpretive research is to provide the contextual information necessary to permit judgement by the reader about the applicability of the research findings. The aim of this study was to achieve this form of generality of the findings without disadvantaging the participants.

Ethical Issues

Consideration of the ethics of educational research is important in both normative and interpretive research. However, because interpretive research emphasises participatory studies which involve researchers working in the classroom, the researchers need to be very aware of the prospective impact of their presence on the classroom. Use of interpretive research requires implementation of strict ethical guidelines because "it is essential to ensure that the interests of participants... are not diminished by participating in the study" (Tobin, 1992, p. 105). Ethical tenets described by House (1990) - mutual respect, non-coercion, non-manipulation between researcher-participant and other participants - were applied to this study by (1) explaining the purpose of the research, (2) keeping participants informed of the progress of the research, (3) sharing with them transcripts of observations and assertions, and (4) maintaining their anonymity.

It is necessary also to guard against researcher arrogance which is manifested in failure to be open with participants about how the research is to be conducted. When designing this study, procedures were discussed with the participants before the study commenced, and the confidentiality of the participants was respected. However, when discussing the purpose of a research study care must be taken because, according to Ball (1988), the desire for openness must be tempered by the realisation that the more open the researcher is about the study, the greater is the likelihood that the practices under study will be disturbed, thereby invalidating the research
approach. A fine balance needs to be achieved, therefore, between the participants' need to know about the study and the influence that that knowledge might have on the activities of the participants while the study is taking place. This issue was especially significant in this study where teachers were informed by the researcher of the importance to the study of metaphors in classroom language. Their awareness might have caused them to be more cognisant of their use of metaphor in their teaching and, as a consequence, caused them to modify their use of metaphor in science lessons.

DATA ANALYSIS

In interpretive research studies, on-going data analysis is an important process. In this study, data analysis consisted of analysis of transcripts of both classroom discourse and interviews. In the transcripts, students who could not be identified were designated as 'S'. An effort was made to identify the number of students involved in recorded verbal exchanges.

As the transcripts were constructed from the recordings of classroom discourse they were examined for segments of language which represented references to the nature of science. These segments were highlighted. Use was made of the qualitative language analysis program called Non-numerical Unstructured Data Indexing Searching and Theorising [NUDIST] (Richards & Richards, 1990) which was used to search for words or expressions used by the three teachers in their classroom discourse in order to compare the meaning which each ascribed to these words.

The material which emerged was less voluminous than the transcripts and provided the starting point for developing assertions, or inferences, which related to: (1) the personal philosophies of teachers, (2) the meanings of metaphor and analogy used in science lessons, and (3) the value of metaphor and analogy in establishing a framework for an individual's personal philosophy of science.

Because of the need for rigour in interpretive research, it is important that the data are available in sufficient detail to support the assertions. Lythcott and Duschl (1990) use Toulmin's concept of warrants to discuss the rigour
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which researchers should apply to the reasoned development of assertions from data. According to these researchers, the reliability and validity of an interpretive investigation depends, to a large extent, on the use of legitimate warrants to interpret data. For example, if one of the warrants which a researcher wishes to use is that use of novel language by individuals reflects actual knowledge of that person, it would be possible to use this warrant only if the language was introduced by the interviewee and not by the interviewer.

Justifiable analysis of data was one of the major foci of this interpretive study. Once profiles of teachers' personal philosophies of science were developed from data of classroom observation they were compared and contrasted with the philosophies of science of key philosophers presented in the model shown in Figure 1 (see Chapter Two). Chapter Four presents specific assertions about teachers' personal philosophies of science that are based on interrelating the theoretical framework of Chapter Two with data collected by using the research approach described in this chapter.

These specific, or within-case, assertions theorise about each participating teacher's personal philosophy of science. The evidence that supports these assertions is presented also in Chapter Four. In Chapter Five, general assertions that were developed as a result of a comparison of the specific assertions are presented. General assertions are theories that describe the relationship between teachers' beliefs about the nature of science and their teaching practices. Erickson (1986) calls these general assertions concrete universals. According to Erickson (1986), case studies provide the necessary evidence for generating warranted general assertions because case studies provide both detailed evidence from each study and the basis for a comparison of the findings from a number of cases. Chapters Four and Five of this thesis describe how the three case studies of this research provided the evidence necessary for the generation of both specific and general assertions.

A single report of the study was prepared in the form of this thesis. Because of its critical nature, the final report was not presented to the teachers involved in the study. However, the teachers were involved in the
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data analysis stages of the study and were given opportunities to validate the assertions that are presented in Chapter Four.
CHAPTER FOUR

TEACHERS' PHILOSOPHIES: IMPACT ON TEACHING PRACTICE

INTRODUCTION

The model of philosophical theories which was generated from the literature review (see Figure 1 in Chapter Two) provides an interpretive framework that consists of central philosophical features - ontology, epistemology, theory building - on which to site teachers' conceptions of the nature of science. The model was designed to enable an interpretation of the personal philosophies of science of three teachers who participated in this study (see Chapter One). The interpretive research methodology, which is described in Chapter Three, was implemented to facilitate collection and analyses of data from classroom discourse. In this chapter these theoretical and methodological aspects of the study are combined in order to (1) interpret each participant teacher's personal philosophy of science, and (2) assess the influence of their personal philosophies on their respective teaching practices and classroom environments.

This chapter is organised into five major sections. In section one, salient aspects of the literature review that have been employed in the interpretive data analysis in this chapter are summarised. Pedagogical implications of beliefs in philosophical theories such as scientific realism, objectivism, and non-foundationism are described.

Section two presents a discussion of the contexts of the three teachers' science classrooms, in particular, the classroom context, curriculum context, and classroom management context, which influenced the teaching practices and student interactions reported in this chapter.

Sections three, four, and five present case studies of the individual teachers - Frank, Greg, and Peter. Data from transcripts of classroom discourse and interviews are used to warrant assertions about the relationship between each teacher's personal philosophy of science and their teaching practice.
Chapter Four

INTERPRETIVE FRAMEWORK: A SUMMARY

This section provides an overview of the main features of the literature review which frames the subsequent analyses of teacher conceptions of the nature of science.

Realism and Observation

Ontology is concerned with the relationship between reality and natural phenomena. The philosophical theories which variously describe this relationship are called naive realism, scientific realism, critical realism, and idealism. The view that scientific objects, such as light rays, electrons, food chains, and orbitals, which have been described as the result of a scientific theory, exist as real objects independent of the theory is called naive realism (Hodson, 1988). According to Tobin (1990), for naive realists, the senses are conduits between the real world and the body through which truth, in the form of observations, is conducted.

The belief that observations of nature are true representations of reality is a form of naive realism that is associated with inductive-empiricism. Positivists also can be described as naive realists, although they tend to ignore ontological questions because positivism requires that all theoretical entities be verified by observation. However, verification by observation is difficult, if not impossible, to achieve if entities such as electrons, food chains, and charms cannot be observed but must be inferred. For positivists, objects that are described in scientific theories exist in nature to be discovered by observation, and can be verified by experimentation.

Inductive-empiricists emphasise the application of observations and experimentation to determine how nature behaves, and place secondary importance on developing scientific theories (Kuhn, 1977).

Inductive-empiricists and positivists require observations to be theory-free, that is, to be made without any preconceived notions. This aspect of their philosophies has been criticised by other philosophers (Hanson, 1959) and by scientists (Einstein & Infeld, 1938; Medawar, 1967) who argue that these philosophies falsely represent the way that science is constructed by scientists.
Pedagogical Implications

The main pedagogical implication of naive realism is the emphasis which it places on observation as a way of discovering scientific truths. A subsidiary implication is that these observations are free of the distortions of theoretical beliefs. Both inductive-empiricist and positivist perspectives of the nature of science emphasise these aspects in their conceptions of reality. Teachers with these perspectives would be expected to emphasise the primacy of students’ observational activities.

The Status of Knowledge

Epistemology is the branch of philosophy that is concerned with questions about the status of knowledge. Naive realists subscribe to the epistemological theory of foundationism which argues that scientific knowledge exists as indubitable facts. Naive realists also accept the epistemological theory of objectivism which promotes the view that knowledge is an entity which can exist externally to cognising beings and can be found in sources such as books, reports, computer programs and libraries. The claim that knowledge can exist as an independent ‘body’ indicates an objectivistic conception of the status of knowledge. According to objectivists, knowledge is a product of the human mind, and once created, has an inherent objectivity, that is, a concrete existence external to the mind.

A more recent definition of objectivity is based on the idea that it is an intersubjective construct. Scientific knowledge constructed in this way has autonomy and external character and is independent of individual subjectivity (Ernest, 1991). This definition of objectivity would not be acceptable to Poppereans because, from their perspective, some knowledge is inherently objective and exists in World Three. However, it may be more acceptable to Lakatosians who have a perspective of shared scientific endeavour with their theory of scientific research programmes.

However, not all objectivists are naive realists. Some objectivists subscribe to the ontological theory of scientific realism which claims that there is no truth correspondence between scientific theories and reality. Instead,
scientific theories attempt to describe reality. Scientific realists believe that, as scientific theories become more sophisticated, they describe reality more closely but never exactly describe reality. As a consequence, scientific realists hold a non-foundationist conception of knowledge which views scientific theories as tentative and scientific knowledge, therefore, as constantly subject to change. As noted in the literature review, for Polanyi, scientific knowledge is constructed by human beings as they search for reality. This view of science forms the cornerstone of his philosophy of science.

Scientific realists are either objectivist (e.g., Popper and Lakatos), or constructivists (e.g., Kuhn, Toulmin and Polanyi). Constructivism is an epistemological theory which claims that all knowledge is constructed by cognising beings and, therefore, cannot exist externally of the knower. According to constructivists, scientific knowledge develops as a result of negotiated understandings.

Pedagogical Implications

Teachers who are naive realists would also be expected to believe that scientific knowledge is secure and unchanging, and that it possesses an inherent objectivity. Teachers' belief in objectivism can be inferred from the metaphors which they use in the classroom. These metaphors may include the conduit metaphor (Reddy, 1979) which signifies the existence of knowledge as material which can be transferred from the source, such as the teacher, to the vessel, such as the student.

Teachers can be described as scientific realists if they believe that scientific theories arise from increasingly accurate attempts to explain a reality which ultimately humans can never know with certainty. Scientific realist teachers would be expected to emphasise the tentativeness of scientific knowledge. Because scientific realists can be either objectivists or constructivists, teachers who are identified as scientific realists could support either the philosophy of constructivism or the philosophy of objectivism. Constructivist teachers would be expected to (1) accept student prior understandings and use them as a springboard from which to encourage students to develop new understandings, and to (2) facilitate
the development of student understandings of scientific knowledge by acting as covert arbiters of scientific knowledge in the classroom community. Because objectivist teachers believe in the transferability of scientific knowledge they would be expected to use teaching practices which promoted the concept of knowledge transfer from an authority figure, such as the teacher, to the student.

Theory Building

For objectivists, the selection of the best scientific theory to explain phenomena is based on the use of a particular methodology but, according to constructivists, both intrinsic and extrinsic features of the scientific discipline influence theory building. The endorsement of a particular method for selecting the most appropriate scientific theory is called absolutism. Some forms of absolutism, such as falsificationism, which was espoused by Popper, and the development of scientific research programmes, which was espoused by Lakatos, have support in the wider philosophical and scientific fields (Medawar, 1967; Phillips, 1987) because they are viewed as being effective and accurate explanations of how science develops.

It is argued that, although inductive-empiricists do not elevate scientific theories to the same prominence which they enjoy in the philosophies of Popper, Kuhn and Lakatos, inductivism can be described as an absolutist mechanism which is based on the use of observation and experimentation to induce generalisations which, with continual evidential support, become laws. Positivists elevate laws to greater prominence in theory building than do inductive-empiricists because they believe that laws can be verified empirically and, therefore, are not associated with the problems of verifying the theoretical components of scientific theories.

According to Kuhn, scientific theories form part of a paradigm. Scientists operating within the paradigm search for confirming evidence for scientific theories which belong to that paradigm. However, not all the evidence can be confirming, and when the evidence becomes too anomalous some members of the scientific community within the paradigm agree to overthrow the old paradigm and associated scientific
Theories, and install a new paradigm which is supported by a new set of scientific theories.

However, Toulmin (1972) claims that new theories arise as conceptual innovations from the evolution of older theories. This evolution can occur only with the consensus of members of the scientific discipline where the innovation is taking place. Toulmin believes that examination of historical development of science is essential to generate assertions about the practice of scientists, both individually and collectively.

**Pedagogical Implications**

Teachers who emphasise the building up of facts, perhaps hierarchically, as the way in which science develops present an inductive-empiricist view of science. For these teachers, the development of scientific theories is not nearly as important as accumulating scientific facts. Teachers whose main concerns are (1) that students use theory-free observations to formulate hypotheses which can be tested by experimentation for verification, and (2) the establishment of scientific laws as the basis of scientific knowledge, can be described as promoting a positivistic conception of theory building. Some teachers with a positivistic conception of theory building would expect students to be able to formulate theories from the observations which they make in the science classroom.

Because of their views on theory building, both positivists and inductive-empiricists would be expected to support a 'cookbook' approach to the conduct and reporting of experiments in science lessons. This approach requires, firstly, the formulation of a purpose in the form of a question, aim or hypothesis which can be answered or proved by experimentation just like the purpose of a recipe is to make something by following steps and using ingredients. The problem of this approach to doing experiments in the classroom is that it implies that there is only one correct way of doing science which, in turn, reinforces an absolutist approach to acquiring proven knowledge.

Teachers who encourage students to formulate their own hypotheses from within the web of a theory, that is, to make 'conjectures' and to test them
by experimentation to determine whether the hypothesis can be falsified can be described as having a Popperean or hypothetico-deductive conception of science. If pedagogical attention focuses on the scientific viability of supplementary hypotheses to explain data which does not support the central scientific theory then science would be taught from within a Lakatosian scientific research programme framework.

There are other formulations of theory building frameworks within which teachers can develop their pedagogy. If teachers emphasise problem solving, use historical examples to illustrate how science changes, and use student groups to role play the sorts of interactions in which scientists are engaged, then they could discuss scientific change in terms of revolutions as proposed by Kuhn, or gradual change as concepts evolve, as proposed by Toulmin.

Critical Realism and Idealism

Critical realists do not differentiate between observation and theory. Instead, they argue that knowledge forms a continuum that ranges from knowledge which derives from personal experience to knowledge which is developed in the form of abstract propositions based on reasoned argument. According to their philosophical theory, there are no entities which can be described as facts because humans create their own reality. Critical realists accept, therefore, that knowledge is constructed by knowing beings and, as a consequence, they support a constructivist epistemology. Of all the philosophers examined in Chapter Two only Feyerabend may be described as a critical realist.

Within the schema discussed in Chapter Two, idealists who perceive reality as an individual human construct have much in common with critical realists. However, their acceptance of the existence of proven knowledge places them in a separate epistemological orientation.

Pedagogical Implications

The main pedagogical implication of critical realism is that teachers would not dichotomise facts and theories. Instead teachers who are critical
realists would be expected to emphasise a transition from knowledge gained from personal experience to knowledge which is based on reasoned argument. All knowledge, regardless of its source, would be valued by the teacher, and the teacher would be responsible for encouraging students to develop their critical reasoning skills. The classroom would be very student-centred, and acceptance of knowledge would depend on shared understandings.

Implications for this Study

Evidence for claims about the pedagogical implications of beliefs about the nature of science were sought in the classroom discourse of teachers. In particular, evidence was sought on the existence of teacher beliefs relating to: (1) the existence of secure knowledge; (2) foundationism or non-foundationism; (3) objectivism or constructivism; (4) the features of theory building; and (5) scientific knowledge and its relationship to reality.

CONTEXTS OF THE STUDY

In addition to the teachers' beliefs about the nature of science there are many factors that influence the teaching and learning activities of the classroom. Of particular note are the three factors of: classroom structure, curriculum, and classroom management. This section of the chapter discusses these factors which constituted the context within which the relationship between the philosophical beliefs and the practices of the three teachers in the study were examined.

Classroom Context

This section discusses the classroom contexts of the three teachers who participated in the study. Classroom context refers to the physical environments of the school science laboratories which governed the main interactions amongst teacher and students.
Chapter Four

Laboratory Structure

The three science classes that were observed in this study were conducted in purpose-built, school science laboratories that were of similar basic design. The laboratories consisted of peripheral benches and a higher demonstration bench at the front of the class. Students sat at bench-like tables which were situated in the middle of the laboratory. Students tended to use the peripheral benches for conducting practical activities which required the use of equipment such as microscopes, or materials such as water which tended to be messy. Figure 4 presents a composite diagram of the three school laboratories that were involved in this study.

![Diagram of laboratory structure]

**Figure 4** Composite diagram of school laboratory structures

In Bacon High, in the school laboratory used by Greg, the chalkboard was situated behind the demonstration bench. At Lakatos High, the screen for the overhead projector (OHP) was located centrally behind the demonstration bench. In this school, Frank used a whiteboard on wheels, and Peter used a chalkboard on one of the side walls or the overhead projector in order to present diagrams and notes to the science class. One of the features of the laboratories at Lakatos High which influenced the use of a transportable whiteboard by Frank and overhead transparencies
by Peter was the existence of a concertina wall behind the demonstration bench. All teachers tended to stand in front of the demonstration bench when they were addressing the whole class.

Science Department Organisation

At Lakatos High, all the science laboratories were situated in a science block which was built on the one level. The laboratories were situated on either side of a long corridor and the science staff room and preparation room were situated in the middle of the block. At Bacon High, the laboratories were situated on three levels. At each level there was a small preparation area and the science staff were situated in small staff rooms on each floor.

Practical Activity Organisation

In Peter’s class, the students worked on practical activities in groups based on the people with whom they sat at the tables. The groups ranged in size from two to four students. In Greg and Frank’s classes there was more variety in group sizes for practical activities. The availability of resources often determined the size of the groups, although, where resources were not a limiting factor, both teachers preferred students to work in groups of two.

Curriculum Context

This section discusses the curriculum context of the three teachers who participated in the study. As discussed in Chapter Three, the science curriculum of the two schools comprised sets of general and specific objectives. Teaching of the general objectives is required by the state Ministry of Education. The specific objectives and the science content in which they are embedded were presented by the Ministry as an acceptable approach to attaining the general objectives of the science curriculum. Because of the difficulties of generating a school-based curriculum most high schools in the state, including Lakatos and Bacon High Schools, implemented the science curriculum developed by the Ministry.
The following science topics were observed during the study (see Section on Science Topics in Chapter Three):

1. Plants and Animals, Transition Science in Frank's class;
2. Energy in the Home, Me and My Environment, This Chemical World in Peter's class;
3. Physical Science including lessons on Work, Potential and Kinetic Energy, Pressure and Buoyancy, in Greg's class.

Specific Objectives and Scientific Knowledge

For the three teachers in this study, the science curriculum framed the science content, and the specific objectives determined the desired learning outcomes. Evidence from the study indicates that the teachers felt that there were time constraints on the development of students' learning outcomes. The teachers assumed responsibility for teaching according to the specific objectives that were described for each science unit.

Specific Objectives and Assessment

The specific objectives, which were written for the ten-week science units into which the curriculum was divided, formed the basis of the summative assessment in each unit. The assessment consisted of two tests, one at about the midpoint of the unit and the other when the unit was due to be completed. The tests were designed to assess student understanding of the specific objectives. Other, less significant forms of assessment, included research assignments and homework assignments. Most of the homework set by the teachers did not form part of the summative assessment.

Although the science curriculum and the subsequent assessment requirements pre-determined the science knowledge and influenced the amount of time that teachers directed to each science topic, the form of their teaching practices was determined largely by the teachers' beliefs about the nature of science. This assertion is examined in greater detail in Chapter Five.
Chapter Four

Classroom Management Context

Classroom management context refers to the amount of time used in the classroom to maintain discipline. Later in this chapter, teacher management of lesson time and practical activities is examined in more detail.

In all the classes involved in the study, the students agreed implicitly to accept the discipline of the teacher. Students were co-operative and, although there were students who often were not on-task, they were not disruptive. The three teachers' classroom management techniques were adequate for maintaining discipline in the classroom. None of the teachers mentioned discipline concerns as a major feature of the management of their classes. Consequently, teachers were largely free to focus on learning outcomes during the lesson.

FRANK'S PHILOSOPHY OF SCIENCE

Frank was a teacher of more than 20 year's experience who had completed a Bachelor of Education degree with a major in biology (see Chapter Three). The class that was observed in this study was described by Frank as comprising average Year 8 students. He explained that Year 8 students who were regarded by the school as the most academically capable had been removed from all Year 8 classes and placed in a separate class. Students seemed quite happy to be in Frank's Year 8 class although, after two months of the first term, Frank did not know the names of many of the students.

Frank selected the science 'content' for each lesson and initiated all classroom activities, whether the activities were based on whole-class, small-group, or individual work. Consequently, his teaching practice may be described as very teacher-centred. Small-group practical work was a significant component of all lessons which were observed in this study. Often students were engaged in more than one experiment at a time. One of the experiments was completed during the lesson and the other was a long-term experiment that required collection of data, such as germination
rates. Frank continually checked the small groups to ensure that they were on-task.

Assertion One

*Frank's teaching practice was underpinned by a coherent and well-articulated positivist personal philosophy of science that was characterised by: (1) a belief in theory-free observations for the generation of scientific facts from which scientific theories emerged; and (2) a conception of scientific knowledge as secure and inherently objective.*

The evidence which warrants this assertion was obtained by examining the field notes and the transcripts of classroom discourse and interviews. A summary of this analysis is presented in this section.

Classroom Interaction

To illustrate the general nature of Frank's teaching practice in his Year 8 class, a typical lesson was analysed according to the types of classroom interactions which occurred. Each classroom activity was classified according to seven types of interactions: (1) classroom organisation (CO), (2) whole-class non-interactive (WCNI), (3) whole-class interactive (Teacher) (WCI(T)), (4) whole-class interactive (Student) (WCI(S)), (5) small-group practical work (GPR), (6) small-group seat work (GS), and (7) individual seat-work (IS) (see Table 5). The lesson was of 60 minutes duration. Each interaction was placed on a time line that indicated the frequency and duration of each type of interaction.

Classroom activities, such as the teacher directing students to open workbooks or directing students to submit homework, have been classified as *classroom organisation* activities. *Whole-class non-interactive* describes classroom activities in which the teacher lectured or demonstrated to the class. *Whole-class interactive* describes activities, such as questioning and responding, that involved the whole class. The letter in brackets signifies who initiated the interaction: S for student, and T for teacher. *Small-group practical work* classifies practical activities which require students to move around the laboratory. *Small-group seat-work* describes activities in which students remain in their seats but interact
### Table 5  
**Classroom Interaction in Frank’s Year 8 Science Class on 1 April 1992**

<table>
<thead>
<tr>
<th>Classroom Interactions</th>
<th>Duration</th>
<th>Classroom Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>2m</td>
<td>Students enter class laboratory and sit down</td>
</tr>
<tr>
<td>WCNI</td>
<td>1m</td>
<td>Frank asks students to open workbooks and homework</td>
</tr>
<tr>
<td>WCITI</td>
<td>2m</td>
<td>Frank reads from workbook about the characteristics of ferns</td>
</tr>
<tr>
<td>CO</td>
<td></td>
<td>Frank disciplines students</td>
</tr>
<tr>
<td>WCITI</td>
<td>2m</td>
<td>Frank draws underground stem and asks students question about it</td>
</tr>
<tr>
<td>WCNI</td>
<td>2m</td>
<td>Frank briefly talks about fern’s underground stems and his farm and briefly mentions roots and asexual reproduction</td>
</tr>
<tr>
<td>WCITI</td>
<td>6m</td>
<td>Frank asks students about the habitat requirements of mosses and ferns using questions from the workbook as a guide</td>
</tr>
<tr>
<td>WCITI</td>
<td>1m</td>
<td>Teacher-student discussion of nutrient requirements of staghorn ferns</td>
</tr>
<tr>
<td>WCITI</td>
<td>2m</td>
<td>Frank asks students questions relating to homework questions</td>
</tr>
<tr>
<td>WCITI</td>
<td>1m</td>
<td>Frank mentions beneficial effects of plants</td>
</tr>
<tr>
<td>WCNI</td>
<td>1m</td>
<td>Students present beneficial effects of plants</td>
</tr>
<tr>
<td>WCNI</td>
<td>4m</td>
<td>Frank loosely reads out the procedure for Activity 10 ‘Investigating the structure and functions of parts of the flower’ from the workbook</td>
</tr>
</tbody>
</table>

- Students carry out observations of flowers
  - dissecting them
  - drawing them
  - answering questions from workbook
  - Students also have access to textbook which contains a stylised diagram of a dichotomous flower

Frank periodically checks student work and assists them to carry out the work

**GPW**  
29m  
Researcher interviews and assist students as they ask questions

**WCNI**  
3m  
Frank goes over questions from workbook and answers them

**CO**  
2m  
Students clean up and pack up

**Key:**  
Classroom Interaction Classifications  
CO - classroom organisation, WCNI - whole-class non-interactive  
WCITI - whole-class interactive teacher initiated, WCITI - whole-class interactive student initiated  
GPW - group practical work, GSW - group seatwork, IS - individual seat-work
with students around them to discuss a particular topic. Individual seat-
work describes activities which require a student to work on their own at
their seat.

The table highlights the significance which Frank attached to the conduct
of small-group practical work which occupied almost half of the total
lesson time. The other interactions which occupied significant segments of
lesson time included whole-class interactive teacher-directed (22.5%) and
whole-class non-interactive (18%). These findings underline two features
of Frank's teaching practice: (1) its teacher-centred character, and (2) the
importance which he attached to the conduct of practical activities in
science lessons. Because the small-group practical work was such a
significant component of the lesson, Frank checked carefully the work of
the small groups as the activity was taking place to ensure that students
were working on the activity.

Frank initiated all the learning activities of the class which was
characteristic of his teacher-centred pedagogy. The major emphasis of the
practical activities was on students making observations of various
phenomena. Students rarely initiated statements or asked questions in a
whole-group situation. Frank used student practical work to maintain
student interest in the science topics which he presented to his Year 8
science class.

Observations and their Significance

Practical activities which emphasised making observations of natural
phenomena formed a significant component of Frank's pedagogy in his
Year 8 class. Frank gave verbal explanations which he supported by
whiteboard drawings and the student workbook. The workbook had been
developed by science faculties from a number of schools to describe the
activities which students were to complete. Examples of observational
activities in Frank's class include: examining and drawing a range of
plants, examining and drawing prepared slides, measuring germination
and growth of plant seeds, and examining vertebrates. These activities
were based on primary materials, such as flowers, samples of different
types of plants, prepared slides that had been collected by the students or
directly from observations occurred when he set the class the task of examining water-transporting cells in vascular plants. Frank's purpose for this activity, which he stated to the class, was to examine transport cells on prepared slides:

Today, I want us to look at the microscope . . . we have some cells in stems, when we look at them, which are specially designed for transporting water. Now, we've applied a stain to some of these so that certain cells will stand out, and those are the big thick-walled ones which transport water. I'll draw them like this [draws them on the whiteboard].

(Classroom Discourse and Field notes, 6 April 1992, p.3)

In this example, the stated purpose of the exercise is only to observe. No theoretical background was provided by Frank. Discussion with students during the lesson indicated that they had little idea of what they were looking for under the microscope or how the transport cells could be recognised. Frank made no reference to any prior knowledge that students might have had in the areas of microscope use or to the structure of any cells which they had observed previously.

Frank's view of knowledge construction seems to be highly congruent with inductive-empiricist and positivist views of science which maintain that the only useful observations are those that are theory-free. This view is at odds with constructivist epistemology which claims that learners enter a learning situation with personal theories which they have built up from personal observations. According to constructivist epistemology, although these theories are modified as learners continually reconstruct their own knowledge, the theories influence the types of observations which learners make. Consequently, no observations are theory-free.

In his teaching practice, Frank's major emphasis on observation with little reference to the development of theory is characteristic of an inductive-empiricist conception of the nature of science. According to inductive-
empiricists, observation of natural phenomena is a significant characteristic of science which separates it from other human endeavours.

Science as Inter-related Facts

Prior to the commencement of this study, Frank had been interviewed about his teaching philosophy for his Year 8 class (Interview, 1991). The video recording indicates Frank's concern about students' knowledge of science and how their knowledge develops. Frank had experimented with an instructional approach that allowed his students to design and develop their own experimental investigations in the science class. However, he was concerned that the students were not relating 'their' experiments to scientific knowledge which they had learnt previously in this science class. For example:

[The experiments the students are doing] have some value but [they are] not really applying [scientific knowledge] and getting . . . to the endpoint of thinking. [that] 'there's a relationship which exists here'.

(Interview, 1991, p. 5)

The concerns which Frank expressed suggest that he viewed science as a hierarchical structure of ideas, and that students should, therefore, understand one layer before they can progress meaningfully to the next. Frank seemed to believe that the role of experimentation is to extend this hierarchical knowledge. This evidence provides tentative support for the assertion that Frank supported an inductive-empiricist conception of theory building as the accumulation of facts.

In the same interview Frank commented that:

[When I'm talking to kids I'll say 'what happens if?' is not really science, because it's almost like magic.

(Interview, 1991, p. 5)

This interview segment highlights the contrasting views about the nature of science of Frank and philosophers of science such as Popper. 'What happens if?' can be viewed as conjecture which emerges as observations occur. Popper regards conjectures as very important to the development
of new scientific theories because they lead people to relate to observations in new and innovative ways (Popper, 1974). However, Frank's concern that students should build on the scientific facts that they had already accumulated is characteristic of inductive-empiricist beliefs about the nature of theory building.

Cause and Effect and Theory Building

Frank's belief in the importance of relating together scientific ideas in terms of cause and effect was demonstrated in his explanations of scientific phenomena. For example, during a period of two lessons (25 & 31 March 1992) Frank used an analogy, in the form of a model, to explain evolutionary aspects of the development of transport systems in plants. His explanations of the analogy indicated that Frank expected students to develop an understanding of the underlying theory by conducting the experiment.

The analogy began when Frank directed the students to construct paper cubes. Frank intended the paper cubes to represent single plant cells. Using a needle, each student poked holes in the sides of their cube. These holes were meant, by Frank, to represent the holes in the cell membrane that permitted the movement of substances into and out of the cell. Subsequently, Frank presented to the class a verbal theoretical explanation of the need for a transport system in multicellular plants that was based on the difficulty of cells in these plants obtaining water or food quickly enough if all movement of materials depended on diffusion between neighbouring cells. Then, students were directed to glue four paper 'cells' together to represent a multicellular plant, and to glue a straw to the side of the cells to represent part of the transport system. Finally, Frank directed students to use a dissecting needle to poke holes in the side of the straw to show how substances, such as water, moved from the transport system to the cells (see Figure 5).

![Diagram of a model of a plant vascular system]

Figure 5  Model of Plant Vascular System.

(Field notes, 31 March 1992, p. 4)
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For a few Year 8 students, the analogy was very effective because it enabled them to explain the relationship between the straw and the transport system in terms of cellular structure and function. However, some of these students seemed confused about the difference between mineral nutrients and food:

Interviewer  So what does the straw represent?
Student     It's something the nutrients pass through instead of going from cell to cell to get to the bottom one. . . . [If that one's the food producer, and the food has to go all through these holes [referring to the holes in the model cells], but instead it can just go down the straw.

(Interview 31 March 1992 p. 8)

For most other Year 8 students, however, the analogy was less effective possibly because Frank's explanation focussed student thinking on the structural aspects rather than on the functional aspects. For these students, it is likely that the analogy was so far removed from their lexicons of experience that it was of little use in helping them to visualise the relationship between the cells and the vascular system of plants. The following extract of an interview illustrates this point:

Interviewer  Have you made yours already? [Referring to the model.]
Student      Yeah.
Interviewer  Has it got holes in it?
Student      Yeah.
Interviewer  Where are the holes?
Student      See along there. [Points to the holes in the model cells.]
Interviewer  Should there be holes in the straw or not?
Student1     There's no holes in the bottom of it, but there's one really big one in the top. [Points to the normal opening in a straw.]
Student2     Yeah.
Interview    Ah. So the straw doesn't need to have holes?
Student      No. It's already got holes on the top and on the bottom.

(Interview, 31 March 1992, p. 8)
Once students' models were constructed, Frank used them to elaborate further on the theoretical framework of the transport system, especially its horizontal and vertical organisation. However, the analogy was a source of conceptual confusion because Frank developed the theoretical framework by referring to a multicellular plant's need for water which he compared with a human vascular system that transported food. This comparison between the two transport systems led to student conceptual confusion which is evident in the student interview (see Interview on page of this Chapter). Students might have developed a more complete understanding of plant vascular systems if Frank had discussed the limitations of the analogy which he used.

Frank's use of this analogy to account for the development of transport systems in plants was designed to help explain to students the theoretical relationship between vascular plants, multicellularity and terrestrial habitats. His explanation of cause and effect, that is, that the need for water led to the development of vascular systems in plants represents a positivistic philosophy of the nature of science (Eels & Sober, 1983). Also, Frank's failure to explain explicitly to students the significance of the analogy is evidence that he expected students to develop an understanding of the theory entirely from the practice of constructing the model. This provides further evidence of Frank's expectation that scientific theory can percolate up to the students' minds from the practical activity. Frank's expectation that theory would percolate up from observations is congruent with a positivistic philosophy of theory building which assumes that theory postulates emerge by 'empirical seepage' from observations (Feigl, 1969; Greenwood, 1990).

Teaching and Learning as a Journey

As discussed in Chapter Three, metaphorical analysis is a useful tool for assessing the implicit conceptions of teachers. Frank used metaphors extensively in his teaching and they tended to have two main purposes. The first was to provide linguistic short-cuts between himself and the students in his class and the second was as personal referents which defined his role as a teacher.
Chapter Four

*Linguistic Shortcuts*

The linguistic shortcuts do not necessarily highlight features of Frank's philosophy of science but they were used extensively by Frank in his classroom discourse. Nevertheless, Frank's belief that students generate meaning from his metaphorical shorthand is consistent with his belief that students generate theory from limited observational data. These metaphors were used by Frank to introduce humorous connotations in his language in order to make students quickly aware of his expectations. For example:

If you don't answer your questions you'll be here forever and a day.

(Classroom Discourse, 1 April 1992, p. 12)

This is an expedient way of saying: 'you should have started answering the questions at the end of the section. If you haven't done so by now you are working too slowly'. Another example of Frank's use of metaphor as a linguistic shortcut is the following statement that he directed to the class:

Let's get our brains going.

(Classroom Discourse, 6 April 1992, p. 1)

This is a quick way of saying: 'I am waiting to hear your well-considered responses to my question but no one is responding as I would like. Therefore concentrate on thinking about an answer to the question.'

*Teaching and Learning as a Journey*

Tobin (1990) argues that some metaphors are *personal referents* that are not shared by teachers, generally, but relate to the individual teacher's implicit beliefs about her or his role in the teaching and learning process. According to Tobin (1991), a teacher's perceived role influences both their teaching practice and their classroom management strategies. In this study, Frank's implicit beliefs about his classroom role and his conceptions of science and the teaching and learning process have been inferred from metaphors which Frank used in his classroom discourse.

Frank's use of metaphors as personal referents indicates that he viewed teaching and learning as a dangerous journey along a narrow track. The
journey metaphor has been identified also by Taylor (1992) in a case study of a high school mathematics teacher. In Frank's case, science constitutes the rugged terrain which had to be negotiated by following the narrow track. The slightest slip off the track could lead a student or a teacher to grief. The teacher and the text were the pathfinders, and only they knew the way. This assessment is supported by numerous metaphors which were embedded in Frank's classroom discourse:

Not bad class considering we had four things to get through.  
(Classroom Discourse, 7 April 1992, p. 3)

We're proceeding one step further past ferns.  
(Classroom Discourse, 1 April 1992, p. 6)

We've got to keep moving fellows, we can't get bogged down.  
(Classroom Discourse, 1 April 1992, p. 8)

Can you see what I'm driving at?  
(Classroom Discourse, 31 March 1992, p. 1)

Which way are you going?  
(Classroom Discourse, 1 April 1992, p. 6)

Just follow along with me.  
(Classroom Discourse, 1991, p. 2)

The conception of science which is implicit in Frank's above use of metaphor is consistent with Assertion One. Because science formed the terrain on which Frank and his students were travelling, knowledge about science had a concrete existence that was external to Frank and his students. Therefore, scientific knowledge was conceptualised by Frank as objective knowledge. Frank's role of pathfinder is indicative of his belief that he was responsible for the selection of the path along which he and his students were to travel. This role assumes that only the teacher has the skills necessary to select the content and the method of learning. Also his apparent belief that his conception of the terrain corresponded to the reality of the terrain is indicative of naive realism. Frank's use of metaphors in this manner provides further evidence of his teacher-centred pedagogy, his objectivist epistemology and a naive realist ontology.
Chapter Four

Frank's compartmentalisation of knowledge into segments highlighted further his objectivist epistemology, as indicated in the following interview excerpt:

Tomorrow we've got a practical looking at a flower and I want them to look at some cones. We haven't done conifers very much yet.

(Interview, 6 April 1992, p. 8)

This is further evidence that Frank's personal philosophy exhibited many of the features characteristic of both inductive-empiricism and positivism, namely, belief in the power of observation, the practice of an absolutist scientific method, support for secure and objectivist knowledge, belief in the power of facts, and the notion that theories emerge from these facts.

Summary

Frank's promotion of observation as the basis of science indicates an empiricist view of science in which observation is equated with fact. His belief in the importance of observation to science was revealed in both his comments to students and his pedagogy. Frank's personal philosophy, which was clearly articulated and coherent, indicated an inductive-empiricist conception of science as facts, and a positivistic conception of theory building in which theories emerged through meanings developed from observations.

Frank's belief in a scientific method that was characterised by promotion of observation as a method for revealing scientific facts and the subsequent percolation of scientific theory influenced his practice in the classroom to the extent that student practical activities were based largely on making observations. As a consequence, a strong relationship was apparent between Frank's beliefs about the nature of science and his teaching practice. This strong relationship can be attributed to the coherence of his personal philosophy of science.

GREG'S PHILOSOPHY OF SCIENCE

Greg was a teacher of 25 year's experience. Although his original teaching area was physical education he had taught science for more than 22 years.
He completed a Bachelor of Education degree with a major in biological science early in his career but, because he believed that he did not have a full complement of science subjects, he had enrolled recently in a Bachelor of Applied Science degree course which had an emphasis on physics as well as biology. However, Greg did not complete this degree because he was encouraged to enrol in a Postgraduate Diploma in Science Education program and, subsequently, completed a Master of Applied Science with a major in science education.

Greg nominated his Year 10 science class for this study. As mentioned previously in Chapter Three, his class was studying a physics unit which focused on the topics of work, potential and kinetic energy, pressure in liquids, and buoyancy. Each student in Greg's Year 10 science class had been issued with a text book but, because of the lack of school resources, two different text books were used. Greg identified the class for this study as consisting of students of generally high academic ability, many of whom were attending the school on specialist scholarships. He described them as "top flight" students (Field notes, 27 April 1992, p. 1). Generally, the students in this class were highly motivated to succeed academically, although, according to Greg, academic achievement was not highly valued by a significant proportion of students at the school.

**Assertion Two**

Greg's teaching practice was underpinned by a coherent and well-articulated positivist personal philosophy of science that was characterised by: (1) a belief that scientific knowledge is inherently objective and secure, which conflicted with his explicit claims about the nature of scientific knowledge; (2) a belief that all natural phenomena follow natural laws that can be verified by experimentation; and (3) a conception of theory building as an accumulation of scientific laws.

The evidence which warrants this assertion was obtained by examining field notes and transcripts of classroom discourse and interviews. A summary of the analysis of Greg's practice is presented in this section.
Classroom Interaction

To illustrate Greg's teaching practices in his Year 10 science class, one of his lessons was analysed on the basis of the types of classroom interaction which occurred during the lesson (see Table 6).

The categories into which classroom interaction was classified were based on the same categories that were used to analyse types of classroom interaction in Frank's Year 8 science class, namely, classroom organisation (CO), whole-class non-interactive (WCNI), whole-class interactive (Student) (WCI (S)), whole-class interactive (Teacher) (WCI (T)), small-group practical work (GPW), small-group seat-work (GSW), and individual seat-work (IS).

Because the lesson was of a 60-minute duration, a 60 minute timeline was used. It was difficult to select a typical lesson because Greg used a range of media such as video, demonstration, and chalk board, and a number of lessons were dominated by demonstrations, lectures or individual student work, rather than by small-group practical activities. However, the lesson which is analysed in Table 6 contains a significant practical component.

Table 6 indicates that Greg controlled almost all instructional activities, including practical activities, seat work, and whole-class interaction, which took place in his Year 10 science classroom. Greg's control in the class was a common feature of all lessons which were observed. At times, students initiated discussion in a whole-class situation by asking questions of Greg. This student-initiated interaction, however, was restricted to a small number of students in the class.

The analysis of this lesson indicates that small-group practical work occurred for about 40% of the lesson and whole-class non-interactive for about 20% of the lesson. Student-initiated whole class interaction occurred for less than 2% of the total lesson time. The results of this analysis highlight the teacher-centredness of Greg's classroom instruction. Greg dominated whole-class activities and prescribed all activities that students conducted. The results indicate also that group practical work was a significant interactive component of the lesson.
### Table 6

**Classroom Interaction in Greg's Year 10 Science Class on 10 June 1992**

<table>
<thead>
<tr>
<th>Type of Interaction</th>
<th>Duration (minutes)</th>
<th>Brief Description of Main Classroom Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>5m</td>
<td>Students wait outside laboratory to be admitted</td>
</tr>
<tr>
<td>WCNI</td>
<td>2m</td>
<td>Greg admits students into class and directs them to open their folders</td>
</tr>
<tr>
<td>WCNI</td>
<td>3m</td>
<td>Greg describes the procedure for an experiment on Buoyancy which students are to carry out in groups based on tables. No mention of purpose of experiment</td>
</tr>
<tr>
<td>WCNI</td>
<td>1m</td>
<td>Greg writes heading &quot;Buoyancy&quot; on chalkboard and students write this in their book</td>
</tr>
<tr>
<td>WCNI</td>
<td>3.5m</td>
<td>Greg describes the experiment in more detail and draws on board diagram of experiment which students are to copy into their books as the procedure</td>
</tr>
<tr>
<td>WCI(T)</td>
<td>0.5m</td>
<td>Greg interacts with students on reading comics</td>
</tr>
<tr>
<td>GPW</td>
<td>7m</td>
<td>Students conduct experiment</td>
</tr>
<tr>
<td>WCI(T)</td>
<td>4.5m</td>
<td>Greg calls for student observations and through judicious questioning and statements leads students to supply the scientifically required observation</td>
</tr>
<tr>
<td>WCI(S)</td>
<td>0.5m</td>
<td>This leads student to initiate question on mechanical advantage</td>
</tr>
<tr>
<td>WCNI</td>
<td>1m</td>
<td>Greg describes the result of the experiment</td>
</tr>
<tr>
<td>GPW</td>
<td>3m</td>
<td>Greg directs students to repeat the experiment with a different sized rubber stopper</td>
</tr>
<tr>
<td>WCI(T)</td>
<td>2m</td>
<td>Greg asks students to predict the feature of corks which causes the observed differences</td>
</tr>
<tr>
<td>WCNI</td>
<td>2m</td>
<td>Greg introduces next experiment by explaining how overflow canisters work</td>
</tr>
<tr>
<td>WCI(T)</td>
<td>2m</td>
<td>Greg describes how electronic balances work and a student explains how the balance can be used to weigh water</td>
</tr>
<tr>
<td>WCNI</td>
<td>1m</td>
<td>Greg directs students to make up results chart using information from the board</td>
</tr>
<tr>
<td>GSW</td>
<td>6m</td>
<td>Students design results chart which they are supposed to show Greg before they start doing the experiment which involves using overflow canisters and balances to measure the amount of water displaced by a rubber stopper</td>
</tr>
<tr>
<td>GPW</td>
<td>2m</td>
<td>Greg returns homework assignments while students work on experiment</td>
</tr>
<tr>
<td>GPW</td>
<td>6m</td>
<td>Students carry on with experiment and Greg visits groups to check their working</td>
</tr>
<tr>
<td>GPW</td>
<td>3m</td>
<td>Greg directs students to clean up. They are running out of time.</td>
</tr>
<tr>
<td>WCI(T)</td>
<td>2m</td>
<td>Greg asks student for result and then mentions what results should be and expands on the outcome. (Some students have done this experiment before)</td>
</tr>
<tr>
<td>CO</td>
<td>3m</td>
<td>Students pack up</td>
</tr>
</tbody>
</table>

**Key:**
- Classroom Interaction Classifications
  - CO - classroom organisation, WCNI - whole-class non-interactive
  - WCNI(T) - whole-class interactive teacher initiated
  - WCNI(S) - whole-class interactive student initiated
  - GPW - group practical work, GSW - group seat-work, IS - individual seat-work
The Journey Metaphor and Greg's Epistemology

Like Frank, Greg also used the journey metaphor for teaching purposes. For Greg, the 'track' which allowed the teaching-learning journey to be completed was the curriculum which must be followed closely:

Well, you're pretty well on track there.

(Classroom Discourse, 28 May 1992, p. 5)

Let's not get side-tracked . . .

(Classroom Discourse, 11 June 1992, p. 2)

A couple of these are obvious and I'm going to skip over them.

(Classroom Discourse, 11 June 1992, p. 7)

We're getting warmer. We're on the right track.

(Classroom Discourse, 10 June 1992, p. 3)

Take a short-cut here.

(Classroom Discourse, 9 June 1992 p. 3)

I don't think we've done density.

(Classroom Discourse, 11 June 1992, p. 9)

Greg seemed to believe that his role was to keep students on the right track and, as a consequence, it was important that he control the classroom environment. Students were expected to listen to his instructions and to follow them closely. The prevalence of this metaphor in Greg's classroom discourse is evidence of his teacher-centredness. For Greg, science knowledge exists 'out there' and forms the terrain along which the students journey with the teacher. Greg's conception of his role as pathfinder also provided evidence of his belief in objectivism. He believed that he was the only person in the classroom with the knowledge necessary to negotiate adequately the science terrain and complete the prescribed curriculum journey.

Greg used other objectivist metaphors. His use of knowledge as a parcel implies that science consists of objective parcels of knowledge, each of which can be picked up, carried around, and passed from one person to another:
So we can wrap that all up. (Classroom Discourse, 11 June 1992, p. 5)

The use of this metaphor in his Year 10 science class implies Greg's belief that scientific knowledge is inherently objective. As a consequence, scientific knowledge has an existence that is external to both teacher and learners and can be transferred from the teacher to the students.

The objectivist nature of Greg's epistemology is evidenced also by the knowledge as a body metaphor which Greg used to describe the procedure of a practical activity that students were required to complete in their science class:

You people can fill in the gaps with your experiments. I'll give you the basic skeleton and you are capable of filling in the gaps. (Classroom Discourse, 10 June 1992, p. 4)

This metaphor implies that Greg conceived of science knowledge as a body. The skeleton of this body is made up of scientific laws or theories; the flesh is provided by the experiments which students conduct; and, to expand the metaphor, tendons which connect the flesh to the bones are supplied by observations. The presence of this metaphor in Greg's classroom discourse helps to explain his promotion of experimentation as an activity designed to produce confirmatory observations of scientific laws.

Greg's use of both teaching as a journey and knowledge as a parcel metaphors in his classroom discourse highlights his perceived need to maintain control of learning activities in the classroom. For example, in his role as pathfinder he maintained control by operating as the source of scientific knowledge in his classroom. Greg's use of these metaphors signify his beliefs (1) that knowledge originates from the teacher, and (2) that it is the teacher's responsibility to transfer parcels of knowledge to the students. These beliefs are consistent with a belief in the existence of external knowledge, and identifies Greg as a proponent of objectivism. A major consequence of Greg's pathfinder role was the implication that all of the information that Greg presented to the students was a true reflection of
reality. This is a naive realist conception of ontology. Greg's realism is discussed further in the segment on realism and foundationism.

Further evidence of Greg's objectivism emerged in classroom situations where students questioned the validity of his scientific knowledge of natural phenomena of, for example, buoyancy and its applications, diving underwater, and conversion of potential energy to kinetic energy. Greg's belief that he possessed true scientific knowledge was clearly indicated in the following whole-class exchanges. For example, in a lesson which focused on the concept of buoyancy, the following exchange between Greg and two students was recorded:

Student 1 If you've got a piece of lead, or something, in the ocean would there be a point where the pressure is so great that it doesn't fall any more? ... Because the Titanic never went to the bottom.

Greg Yes it did!

Student 1 It just drifted along in the currents.

Student 2 They went searching for it.

Greg Oh, is that why they couldn't find it?

Student 1 Yeah.

Greg I mean it wasn't exactly lost. They were given coordinates, where it actually hit the iceberg. It could have drifted with the current as it was sinking. It's on the bottom now.

Student 1 I doubt it. It went down at an angle like this, it might have slid to the bottom.

Greg It might have slid. OK, let's not get sidetracked on the Titanic.

(Classroom Discourse, 11 June 1992, p. 1-2)

From this vignette it seems that Greg believed that some of his authority as a teacher was attributable to his superior scientific knowledge, and that if he was to admit that he could not answer a question then he might lose some of his control in the class. This belief which led him to undervalue students' attempts to understand natural phenomena indicates an
acceptance of the *teacher as controller* metaphor which reinforces Greg's teacher-centred approach to classroom instruction.

Further evidence of Greg's *teacher as controller* metaphor emerged when Greg was lecturing to the students on applications of buoyancy. Greg was talking from notes that he had written on the chalkboard about the swim bladder that bony fish possess. A student questioned Greg's claim that sharks could not stop swimming because they did not have a swim bladder that enabled them to remain buoyant when they stopped swimming:

<table>
<thead>
<tr>
<th>Greg</th>
<th>Sharks ... do not have a swim bladder. So they have to keep swimming to keep themselves at one depth. They have to move and they've wings. Their pectoral fins are their wings. They're basically swimming under water. Now when they come to a stop, they will sink.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student</td>
<td>How did they [the sharks] sleep in that cave then?</td>
</tr>
<tr>
<td>Greg</td>
<td>They were sitting on the bottom. That's the show on sharks?</td>
</tr>
<tr>
<td>Student</td>
<td>Yes.</td>
</tr>
<tr>
<td>Greg</td>
<td>They were sitting on the bottom. They're not bony fish. They're cartilaginous fish but they don't have a swim bladder.</td>
</tr>
</tbody>
</table>

(Classroom Discourse, 11 June 1992, p. 9)

Instead of answering the student's question Greg reiterated the statements which he had made about sharks and swim bladders prior to the question. This vignette provides evidence also of Greg's belief in the security of the scientific knowledge which he presents to students.

**Foundationism and Realism**

As mentioned previously in this section, Greg's use of the journey metaphor implies both a naive realist conception of the nature of science and a foundationist perspective on the security of scientific knowledge. However, Greg was aware of the tentativeness of scientific knowledge, which is a non-foundationist perspective, and talked to students about the
use of empirical data to support or not support hypotheses. The following vignette presents Greg's explicit statements about the tentativeness of knowledge and highlights the implicit images about the nature of science which are embedded in language use. Greg's language, especially when he talked about proving the hypothesis, implies a belief in the permanence of scientific knowledge:

<table>
<thead>
<tr>
<th>Student</th>
<th>The hypothesis is correct.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greg</td>
<td>The hypothesis is never correct. They're merely, what's the word? Starts with ess.</td>
</tr>
<tr>
<td>Student</td>
<td>Guesses.</td>
</tr>
<tr>
<td>Greg</td>
<td>Supported. You support the hypothesis. Because maybe tomorrow it didn't work because we had a piece of equipment that was faulty and sometimes when you're testing differences between certain things and the difference was caused by a variable we didn't know about. So we really need to test this in many different situations and if it's continually supported we think about being confident about that hypothesis and making a law out of it. Now I've proved it today or supported it today. Dozens of people, hundreds of years ago checked it out, it was still working then so it's basically a law now.</td>
</tr>
</tbody>
</table>

(Classroom Discourse, 9 June 1992, p. 2)

The conflict between Greg's implicit beliefs and claims about the status of knowledge are highlighted in this excerpt of classroom discourse. Greg explains explicitly to students that knowledge is tentative but even in this explanation his use of terms such as 'proven' and 'law' imply a belief in the permanence of scientific knowledge.

Although Greg's avowed acceptance of the tentativeness of scientific knowledge suggests that he is a scientific realist, his implicit beliefs signify a belief in naive realism. Evidence from the analysis of Greg's use of the journey metaphor support the inference of naive realism. On the journey, science constitutes the terrain which must be traversed by students and teacher. As a terrain, science has a certain concreteness which is equated
with reality. The acceptance of a correspondence between the terrain and one's perception of the terrain is a naive realist conception.

Furthermore, Greg presented to his students scientific laws such as “force equals mass multiplied by acceleration” (F=ma) as though these laws had always existed in the form in which he presented them. He did not discuss their historical development or their relationship to scientific theories. Greg’s use of this method for presenting scientific laws to his students implies a foundationist perspective on scientific knowledge.

The emphasis which Greg placed on empirical data suggests that he believed scientific knowledge to be secure if it is based on the authority of empirical foundations, and that it was his responsibility to provide students with the experiences necessary to gain this knowledge. According to Phillips (1987) this is a foundationist perspective.

The evidence presented in this segment indicates that Greg’s classroom practice is more consistent with his implicit beliefs about the secure status of scientific knowledge than with his explicit claims of its tentativeness. Although Greg discussed, on occasion, the tentativeness of scientific knowledge, the focus of practical activities and demonstrations in his Year 10 science class was towards confirming scientific laws, an approach that implies that scientific knowledge is based on secure empirical foundations. Thus, while Greg might discuss the tentativeness of scientific knowledge with his students, other aspects of his language, notably, his use of metaphors and the underlying purpose of practical and demonstration group activities had the effect of reinforcing naive realist and foundationist beliefs about the nature of science.

Scientific Laws and Theory Building

As indicated in the previous segment, Greg's acknowledgment of the tentativeness of scientific knowledge did not extend to a consideration of scientific laws and theories. Some of his comments to students imply that theories are not important, and that hypotheses serve merely as convenient starting points for conducting experiments. For example:
It doesn't matter what [the scientist] states provided there is a statement that he makes, and then collects some data to make some sort of comment about the hypothesis.

(Classroom Discourse, 9 June 1992, p. 1)

This extract indicates Greg's conception that scientific knowledge develops through the collection of data. The types of experiments which Greg selected for students to conduct indicate a conception of theory building based on the notion of confirmation of scientific laws by experiment and observation. For example, students carried out an experiment to confirm that pressure increased with depth in a liquid, and another to confirm that potential energy of an object was equal to its kinetic energy as it hit the ground. At times when Greg asked students to develop their own hypotheses, ultimately, he supplied the hypothesis:

I want to test kerosene. I want to find out whether this [pressure increasing with depth in water] will be supported with kerosene. So make up a research question. Now you've got to make a comparison between kerosene and water [brief pause]. You can almost hear the brain cells talking to each other. Ok! Research question: Will the pressure in kerosene increase with depth as it did in water? How's that?

(Classroom Discourse, 9 June 1992, p. 3)

This excerpt highlights Greg's concern that students commence experiments with an appropriate aim or question so that experiments will 'work', that is, they will confirm a scientific law. The reference to 'I' in this vignette provides further evidence of Greg's teacher-centred approach to classroom instruction.

Greg's conception that theory building is based on the confirmability of scientific laws is a narrow conception of the development of scientific knowledge because it does not account for scientific entities which cannot be observed or tested empirically, and promotes the myth that science is based solely on empirical evidence. Such a conception of theory building is consistent with a positivist philosophy of science.
During an interview, Greg indicated that he believed experiments to be an important aspect of school science. However, he claimed also that:

[Experiments] don't teach as much as people say they do because the experiment, in a lot of cases, is not obvious as to what the conclusion is, or if it does work, the kids are not impressed all that much, and they don't relate the conclusion to the general aim.

(Interview, 24 June 1992, p. 3)

Greg indicated that he believed that the objectives of the curriculum could be met more easily by putting notes on the board and by doing a real project in which students carried out 'real' data collection.

These exchanges highlight three aspects of Greg’s beliefs. Firstly, they confirm that the importance which Greg ascribed to the verification of scientific laws and hypotheses is not restricted to student practical work, but that it is a feature of his belief about the way that scientific knowledge grows. Secondly, the exchanges indicate that, although Greg believes that it is important that students conduct experiments, he believes also that science unit objectives can be achieved more quickly by using notes on a chalk board. This implies that he does not consider that the science curriculum is necessarily representative of scientific knowledge. Thirdly, these exchanges provide further evidence of Greg’s naive realism.

The primacy of scientific laws in Greg’s personal philosophy of science is indicated also by evidence obtained from an interview with Greg. When he was asked to give an example of a theory, which he had described as an underlying principle, Greg presented Ohm's Law:

[T]heory to me would be underlying principles. If you had something like Ohm's Law you’d be looking at the relationship between voltage and current and you’d need to be able to apply that if you were working on a circuit or simply just estimating the current you were going to use if you put too many 'piggy back' power points, double adaptors, on the power point.

(Interview, 22 June 1992)
This vignette confirms that Greg equates scientific laws with scientific theories and sites him with positivists. Also, Greg claimed that he looked at nature for confirming evidence about scientific principles.

I like to look at the world around me in physical terms, in an exact type of sense. When I watch ocean waves, I look for diffraction and I look for refraction because I know that it'll be there if it's wave motion.

(Interview, 22 June 1992, p. 1)

These interview statements confirm the concrete existence which Greg attributes to scientific laws, and are consistent with a naive realist ontology and an objectivist epistemology.

Formistic World View

The belief that all natural phenomena follow natural laws is characteristic of a world view called formism (Pepper, 1970). The root metaphor of which is similarity (see Table 2 in Chapter Three). People with a formistic world view seek to classify natural phenomena and search for order in the universe. Greg's description of his search for reflection and refraction in ocean waves provides evidence of this world view:

I can remember standing at Port Campbell watching the waves hit the cliff at 45° and reflect off almost perfectly and cross over the incoming waves. You had those perfect reinforcements and annulments.

(Interview, 24 June 1992, p. 1)

Greg's belief in a world view based on formism is consistent with his personal philosophy of science based on a positivistic conception of theory building which is defined by the accumulation of empirically verified scientific laws.

Student Prior Knowledge

Evidence from the transcripts indicates that Greg was aware of the existence of students' prior knowledge. Sometimes he challenged students' preconceptions about science concepts by using questions and
citing examples from his own experiences. On one occasion, Greg challenged students’ understanding of vertical and horizontal movement of an object under the influence of gravity. However, when students challenged Greg to support empirically his claim that an object would hit the ground at the same time, whether it was thrown vertically or horizontally, Greg averred and stated that they would talk about it later. Although Greg was aware of student prior knowledge, consideration of students’ prior knowledge was not a significant feature of Greg’s classroom practice.

From a constructivist perspective, if Greg had acknowledged seriously students’ prior knowledge and experiences he could have detected incomplete student understandings and used students’ understandings as a base for developing lesson programs. Greg’s instructional approach might have accounted for some of the negative undertones which emanated from students when he directed the class to complete activities that they had completed in previous classes. For example, Greg demonstrated the operation of a Cartesian Diver and asked students to state the principle which explained the phenomenon. A group of students were involved in a quiet discussion of the demonstration:

Student 1  I’ve done all this before.
Student 2   Have you done this unit?
Student 1   It seems like it. (Classroom Discourse, 11 June 1992, p. 7)

Students’ responses to an activity that required them to measure the volume and weight of water displaced by an object also evinced negative comments:

Greg       You weigh the displaced water. Now the way you do that. You have one of those little cans.
            [Greg points to the overflow canisters]
Student    Oh, these again.
Student    I hate it! I hate it!

(Classroom Discourse, 10 June, 1992, p. 4)
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Interviewer  Do you have an idea about what's going to happen when you do the experiment? [Students nod]
Interviewer  What do you think is going to happen?
Student 1   The weight of the displaced water will equal the weight of the object.
Interviewer  Have you done that experiment before?
Student 1   I've done heaps of these experiments before.

(Interview, 10 June 1992, p. 5)

If Greg had asked students about their understanding of science phenomena or the outcomes of experiments prior to organising his classroom activities, he could have afforded himself opportunities to conduct experiments which students might have regarded as being more meaningful and more relevant. A greater awareness of students' prior science knowledge might have ameliorated some of the inconsistencies in Greg's expectations about students' understandings of scientific phenomena.

Relevancy

When students asked Greg to clarify an aspect of a scientific explanation that he had presented to them, Greg often provided detailed explanations and used examples from his own experiences to illustrate a particular point. Greg also used these examples from personal experience and other examples from society in attempts to make science lessons more relevant to students.

For example, Greg's discussion of his attempt, when he was young, to breathe under water by using a hose connected to a floating tin can, and the consequent discussion of the effects of pressure on the human lung, generated discussion about the effects on humans of increasing pressure. Greg also used descriptions from technology, such as the stability of submarines under water and the Plimsoll Line, to make the content of the lesson more relevant to students in his Year 10 class.

The instructional approach of placing science in context is believed by some authors (Mitman, Mergendoller, Marchman, & Packer, 1987) to be
important in improving scientific literacy among school students. Considerations of the applications of scientific laws expanded the focus of Greg's science lessons with his Year 10 science class. Greg's use of personal experiences to describe the application of scientific laws to a wider field outside the classroom provided him with opportunities to share these experiences with his students. However, this instructional approach to making science 'more relevant' did not require Greg to reassess his personal philosophy of science. In Greg's case, therefore, relevancy is like icing on a cake, that is, it hides any imperfections in the cake of beliefs about the nature of science.

Summary

A problem with Greg's personal philosophy of science is that he tended to present science as a solitary activity. He ignored the interaction between scientists which is important to the development of theories. Greg's neglect of theories was consistent with his positivistic philosophy of science that was based on his belief that observations could be related directly to scientific laws.

The increased level of student questioning during Greg's description of his personal experiences and their application to scientific laws, which was a common feature of his lessons, resulted in increased student interest during these segments. However, if Greg had been more aware of student prior knowledge in his science lessons then students might have exhibited a greater interest in other activities which Greg incorporated into his lesson structure.

The most interesting aspect of Greg's personal philosophy of science was the conflict between his espoused and implicit beliefs about the nature of science. This conflict was particularly evident in the contradictions between his overt claims about the tentativeness of scientific knowledge and his implicit beliefs, evidenced in his teaching practice, which indicated his acceptance of the secure status of scientific knowledge. His preoccupation with empirical exercises designed to confirm scientific laws signifies a positivistic philosophy of science which is underpinned by his belief in naive realism and foundationism.
PETER'S PHILOSOPHY OF SCIENCE

For Peter, 1992 was only the second year that he had been employed as a teacher. In 1990 he had completed a Diploma of Teaching with a major in human biology. During this study, Peter was enrolled externally to upgrade his Diploma to a Bachelor of Education degree. Peter was teaching Years 8, 9 and 10 at Lakatos High, and his Year 9 class was selected for this study.

The class was made up of students from a wide range of ability groups. Some students were more active in class than were others and interacted more with Peter during the class. As a group, the class seemed generally positive about their learning activities, although a number of students in the class often were observed to be off-task.

Compared with Frank's and Greg's philosophies, Peter's philosophy of science was difficult to interpret because it was not clearly articulated or conceptualised. Often, there was conflict between what Peter claimed to be important in science and teaching, and what his practice indicated that he believed to be important. As an inexperienced teacher, he had had less time than either Greg or Frank to reflect on both his teaching practice and his conceptions of the nature of science and the development of scientific knowledge. As a consequence, Peter had difficulty describing explicitly his beliefs about the nature of science.

Assertion Three

Peter's teaching practice was underpinned by an inductive-empiricist personal philosophy of science that was not clearly conceptualised or articulated and that was characterised by: (1) a belief in naïve realism; (2) a belief that the authority of the workbook and scientists provided a basis for the security of scientific knowledge; (3) a belief that scientific knowledge is inherently objective and secure; and (4) a conception of theory building in science as an accumulation of scientific facts.
The evidence which warrants this assertion was obtained by examining field notes and transcripts of classroom discourse and interviews. A summary of this analysis is presented in this section.

**Knowledge of Science and Knowledge of Teaching Practice**

Peter claimed that much of his pre-service teacher education had concentrated on preparing him to be pedagogically adept but had neglected to develop his knowledge of his teaching area of science. He claimed that, consequently, he felt confident about being a teacher but felt much less confident about his knowledge of science:

> I probably feel more confident about my approaches to teaching than content. (Interview, 8 April 1992, p. 6)

According to Peter, the study of epistemology was not a feature of any of the preservice courses that he had completed. He believed that the courses had not adequately prepared him to teach science and, as a consequence, his background in science was not thorough.

The inadequate state of Peter's scientific knowledge probably explained his heavy reliance on the student workbooks as the main teaching resource for the various science units that he taught while this study was in progress. The workbooks had been developed by science staff from a number of schools in the school's local area. Although Peter was critical of these workbooks because they "did not cater for a lot of knowledge" (Interview, 8 April 1992, p. 2), he used them extensively with his Year 9 science class. He claimed that his use of these workbooks ensured also that he would adequately address the specific objectives of each science unit.

**Classroom Interaction**

Table 7 illustrates the types of classroom interactions that occurred in one of Peter's typical Year 9 science lessons in which small-group practical work (GPW) was a significant component of classroom interactions. Of
Table 7  
Classroom Interactions in Peter's Year 9 Science Class on  
24 June 1992

<table>
<thead>
<tr>
<th>Classroom Interaction</th>
<th>Duration (minutes)</th>
<th>Brief Description of Main Classroom Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>WCI(T) IS</td>
<td>3m</td>
<td>Peter introduces paper and element analogy. Peter directs students on conduct of activity where students ripped up a sheet of paper into small bits. Peter's instructions and student activity occur concurrently.</td>
</tr>
<tr>
<td>WCI(T) CO</td>
<td>2m</td>
<td>Peter defines element.</td>
</tr>
<tr>
<td>WCI(T)</td>
<td>1m</td>
<td>Clean up.</td>
</tr>
<tr>
<td>WCI(T)</td>
<td>2m</td>
<td>Peter shows OHP of illusion with old woman turning into a young woman.</td>
</tr>
<tr>
<td>WCI(T) WCI(S)</td>
<td>2.5m 0.5m</td>
<td>Teacher-student interaction on structure of CO₂. Student mentions N₂ as breathed out. Peter disagrees.</td>
</tr>
<tr>
<td>IS</td>
<td>3m</td>
<td>Students draw element and compound on sheet.</td>
</tr>
<tr>
<td>WCNI</td>
<td>1m</td>
<td>Peter talks of Zn + S giving ZnSO₄ as example of elements forming compound.</td>
</tr>
<tr>
<td>WCNI</td>
<td>3m</td>
<td>Peter defines molecule.</td>
</tr>
<tr>
<td>IS</td>
<td>2.5m 0.5m</td>
<td>Students draw diagrams on sheet. Discussion between Peter and students on elements needed to make CO₂.</td>
</tr>
<tr>
<td>WCI(T)</td>
<td>2m</td>
<td>Peter defines mixture.</td>
</tr>
<tr>
<td>WCNI</td>
<td>2m</td>
<td>Peter draws on board as students complete drawings on sheet.</td>
</tr>
<tr>
<td>WCNI</td>
<td>5m</td>
<td>Student turn to workbook and teacher goes through procedure of experiment. Includes discussion of dangers of iodine. Students are to observe and answer questions.</td>
</tr>
</tbody>
</table>

Students carry out experiment. Peter distributes Zn and I₂.

Peter moves among student groups checking student work.

GPW 20m

Student interviews are conducted at this time.

Some students have completed the work and Peter reminds them that they should be writing observations and answering questions.

WCI(T) 6m

Whole class interaction as results of experiment, particularly observations are listed. Students start packing up as Peter is explaining what a compound is in terms of being changed from the elements which reacted to form it.

Key:  
- Classroom Interactions Classifications:  
  CO - classroom organisation, WCNI - whole-class non-interactive  
  WCI(T) - whole-class interactive teacher initiated,  
  WCI(S) - whole-class interactive student initiated  
  GPW - group practical work, GSW - group seat-work, IS - individual seat-work

the ten Year 9 science lessons that I observed, only half contained a practical component. This small proportion indicates that Peter attached
less importance to the conduct of student practical activities than did Frank. The amount of practical activity that Peter included in his lessons depended on the emphasis which this type of activity was accorded in the student workbooks.

Table 7 shows that individual seat-work which was initiated by Peter was more evident in his lessons than in those of either Greg or Frank. This work usually required students to copy information from either the chalk board or overheard projector screen in order to complete work sheets. Whole-class non-interactive and whole-class teacher-initiated activities occupied more than a third of the lesson.

This high proportion of teacher dominance in lessons in which practical work was undertaken indicates that, like Greg and Frank, Peter’s classroom instruction was very teacher-centred. Peter’s reliance on student workbooks resulted in a teacher-centred instructional approach that was characterised by Peter’s initiation and strong control of both individual seat-work and student group practical work.

**Foundationism and Theory Building**

Peter’s heavy reliance on the workbooks in his Year 9 science class made him very dependent on the way in which science was represented in the workbooks. Peter believed that the workbooks contained true science knowledge to the extent that he promoted accurately and unreservedly workbook descriptions of scientific method and workbook presentations of scientific knowledge. His beliefs about the development of scientific knowledge have important philosophical implications. Firstly, his belief that scientific knowledge is secure and unchanging is a foundationist perspective on the status of scientific knowledge. Secondly, his belief that there is only one correct way of developing scientific knowledge is an absolutist perspective on theory building.

Peter’s absolutist concept of theory building in science as the accumulation of scientific facts which can be acquired from experimentation or books, is consistent with an inductive-empiricist philosophy of science. As the following vignette indicates, Peter’s implicit
beliefs about science led him to present this very narrow perspective of the nature and development of scientific knowledge to his Year 9 students.

In a lesson on "What we need to have to be alive" (Classroom Discourse, 7 April 1992, p. 1), Peter had asked students to brainstorm the names of activities which represented the "seven life processes" because, he explained to the class, the presence of these processes indicates that something is alive. Peter listed students' responses on the board so that the responses which were the same as the processes listed in the workbook were separate from other responses. This led one of the students to question Peter's organisation of students' responses in terms of the categories of growth, reproduction, excretion, response, movement, circulation, and respiration that were listed in the student workbook. These were the only life processes that Peter would accept as correct answers. Other students also attempted to assert their disparate views:

<table>
<thead>
<tr>
<th>Peter</th>
<th>Can you see the distinct pattern that I'm making? [Peter is recording student responses on the board so that particular responses are placed to the left of a line down the middle of the board.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student</td>
<td>Yeah.</td>
</tr>
<tr>
<td>Tim</td>
<td>'Made of cells' isn't that one of the seven?</td>
</tr>
<tr>
<td>Pria</td>
<td>Yeah, 'made of cells' is one.</td>
</tr>
<tr>
<td>Peter</td>
<td>Is it?</td>
</tr>
<tr>
<td>Student</td>
<td>Yeah, 'made of cells' is one.</td>
</tr>
<tr>
<td>Peter</td>
<td>Have you ever seen a crystal?</td>
</tr>
<tr>
<td>Students</td>
<td>Yeah.</td>
</tr>
<tr>
<td>Peter</td>
<td>Have you ever seen how it builds and builds and builds on each other?</td>
</tr>
<tr>
<td>Students</td>
<td>Yeah.</td>
</tr>
<tr>
<td>Peter</td>
<td>They're made of cells. Is that living or non-living?</td>
</tr>
<tr>
<td>Student</td>
<td>Non-living.</td>
</tr>
<tr>
<td>Tim</td>
<td>But some things can have some of them that other things can't have, but nothing that is living can't have none of them.</td>
</tr>
<tr>
<td>Peter</td>
<td>They're still cells.</td>
</tr>
</tbody>
</table>
Tim  But the thing is, crystals, do they breathe? Do they reproduce? Do they excrete? Do they

Peter  That's right. That's why you can't classify that [points to 'made of cells'] as living because we have crystals that do it and they're non-living.

Student  Yeah, but they're different.

Tim  Yeah, but then everything moves.

Peter  Slightly different.

Student  But why can't we put that down then?

(Classroom Discourse & Field notes, 7 April, p. 2)

Peter could have used this exchange as an opportunity to discuss with his students the methods used by scientists to organise scientific knowledge. In this situation, where there was debate about the characteristics of living things, Peter could have focused on the different approaches which have been used in science to describe the basic features of living things. Instead, Peter's approach, as evidenced in this vignette, reinforced a conception that there is only one true answer in science to the question of what it means to be a living thing and also reinforced the idea that for questions in science there is always one true answer. The conception that there exists a true unchanging answer to scientific questions is characteristic of a foundationist perspective on the status of knowledge. Peter's belief that for these questions there exists only one true answer is characteristic of an absolutist conception of theory building.

The strong emphasis on the workbook tended to lead Peter to present a 'cook book' approach to scientific practice. The cookbook approach promotes the notion that there is only one correct method of doing science. This method is structured so that the practical activity is prescribed in terms of an aim or purpose, and a list of the equipment, or ingredients, that are needed to conduct the procedure, or recipe, of the practical activity. The procedure is designed to provide confirming evidence for the aim, much like a recipe enables a cook to make a favourite cake.

Peter's explanation of the requirement to implement carefully the cookbook approach was that students would be led to the correct answer
if they did so. These right answers confirmed the truths about science which scientists had discovered already. The prevalence of the cookbook approach in Peter's teaching indicates his foundationist perspective on science, and an absolutist inductive-empiricist approach to doing science. In class, Peter often used the authority of scientists to support his claims about the security of the facts of science, and also to emphasise his belief that science is an accumulation of facts:

It's not a question of you getting full marks or not, it's a question of whether that's technically correct.  
(Classroom Discourse, 6 April 1992, p. 4)

There's a couple of terms, concepts which scientists use to dictate what they [matter] are.  
(Classroom Discourse, 22 June 1992, p. 4)

This kinetic theory . . . many scientists use [it] to dictate whether you've got a solid, a liquid, or a gas.  
(Classroom Discourse, 22 June 1992, p. 4)

The above statements indicate that Peter believed that the view of science which he presented was the only correct one, and that this view gained extra credence because it was presented or supported by authorities such as the workbook or scientists.

Science and the Teacher's Role

Peter was the only one of the three teachers interviewed in this study who referred, in explicit metaphorical terms, to his role as a classroom teacher. Peter's perceived role was teacher as facilitator. According to Peter, this role was necessary to allow him to teach science to students in a manner which was consistent with his description of science as discovery.

Interviewer  How would you define science?  
Peter  Probably more of discovery.  
Interviewer  For students also?  
Peter  For the students, yes . . . [T]he teacher acts as facilitator with regards to the knowledge and also giving students a
direction to take. [A] teacher who actually allows the students to discover, for themselves, how the operation of an experiment works or the operation of what's going on.

(Interview, 8 April 1992, p. 1)

Peter seemed to believe that the practice of science in the classroom should mirror the way in which scientists conducted science. As facilitator, the teacher should allow students to discover, for themselves. However, as has been highlighted by the data presented in this case study, Peter's implicit epistemological belief, particularly his absolutist philosophy of theory building, severely restricted the practice of discovery in Peter's Year 9 science class.

Teacher as Controller

Although Peter might have perceived teacher as facilitator to be an educationally correct role to play, evidence from later in the same interview indicates that Peter's teaching practice was very teacher-centred and that he conceived his classroom role more as teacher as deliverer and controller of most of the classroom activity:

<table>
<thead>
<tr>
<th>Interviewer</th>
<th>Do you have a view of what science is?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peter</td>
<td>Gee, I hadn't thought about that, really. All I've thought of, coming out of uni, [is] saying &quot;I'm a teacher&quot;, is trying to effectively get across the information being taught in the objectives to the students in the best way you can. My whole idea is to make it fun. If I can incorporate fun and learning I've succeeded, I think, as a teacher.</td>
</tr>
</tbody>
</table>

(Interview, 8 April 1992, p. 5)

This interview extract indicates that Peter's implicit role-related belief was not teacher as facilitator, but teacher as source of knowledge whose role was "to get across information" to the students. The conception of getting across information belongs to the conduit metaphor described by Reddy (1979). Within the context of the conduit metaphor, knowledge is viewed as an objective commodity which can be transferred from teacher or text to
student. According to this conception of scientific knowledge, the teacher is the source, the student is the vessel, and knowledge is the substance to be transferred. A consequence of Peter's use of the teacher as source of scientific knowledge metaphor was his belief that scientific knowledge exists externally of knowers as an objective entity. In practice, Peter initiated all instructional activities in his class. His teacher-centred approach was consistent with his personal referent of teacher as source of scientific knowledge.

**Science as an Accumulation of Facts**

The explicit statements made by Peter about science as discovery, however, were not supported by his practice. Instead, he tended to introduce new science topics by referring to the title of the science topic and then the science facts which would be presented during the unit. For example:

> 'This Chemical World'. The sort of terms, concepts you'll be looking at is the periodic table. You will know certain elements there. You will know their symbols. (Classroom Discourse, 22 June 1992, p. 1)

> If we break down 'Me and My Environment' you're concentrating on certain organs in your body. (Classroom Discourse, 6 April 1992, p.1)

The use of titles of units to identify the science topic to be taught implies that Peter viewed each topic as consisting of a discrete collection of facts which were to be taught during a particular science unit. This provides further support for the inference about Peter's conception of science as an accumulation of facts. Peter's focus on science facts indicates an inductive-empiricist view of theory building where accumulating facts is more important than developing theories. These statements also provide further evidence of Peter's implicit belief in an inductive-empiricist philosophy of science.

**Student Prior Knowledge**

Peter's teaching strategies utilised occasionally the prior knowledge of students. His use of these strategies was more extensive than was either
Greg's or Frank's use, and included techniques such as brainstorming, asking students to define words that occurred in the workbook, and asking students to read aloud questions from the text. However, these strategies were not used by Peter as integral approaches to presenting the science content of the lesson. He seemed unable to design teaching strategies which incorporated use of student prior knowledge. Consequently, these techniques remained on the periphery of his lessons. Peter's teacher-centred pedagogy and predominant use of workbooks as resources, ensured that the small amount of student-initiated activity which occurred in his Year 9 science class did not affect the presentation of the lesson.

Security of Knowledge and Naive Realism

Peter used analogies, such as models and role play, to help explain theoretical scientific entities such as atoms, electrons and elements to students. For example, he used two models to help explain to students the structure of the atom. The first was the Thompson, or 'plum pudding', model and the second was the Rutherford, or 'solar system', model of the atom. However, both models are out-dated and present a very incomplete conception of atomic structure. When students were interviewed about the nature of these models a range of responses was noted. Some students claimed that the plum pudding model was appropriate because atoms would look like the model if they were magnified enough:

Interviewer: Is that really what an atom looks like?
Student: Not really because it's too small [the atom]. As a rough copy it is like that.

(Interview & Field notes, 1 April 1992, p. 7)

This interview segment suggests that, for this student, the model which Peter had provided represented the structure of an atom, and if an atom was magnified to the same size as the model, they would look the same. This student's view was that a 'real' atom would look like the model so there existed a one-to-one correspondence between the model and the atom. This is a naive realist conception of the nature of reality and its correspondence to explanations of our perceptions of reality. As shall be
shown later in this segment, Peter reinforced naive realist conceptions in his teaching practice.

As the following interview extract indicates, other students seemed to be aware that the models were designed merely to enable visualisation of an atom and were not supposed to be representative of atoms:

Interviewer  Is that really what an atom looks like? [Points to the solar system model of an atom which the student has drawn in their note book].
Student No. It resembles an atom.

(Interview & Field notes, 1 April 1992, p. 9)

This interview segment indicates that this student realised that models of atoms which they had drawn in their note books were not true copies of an atom because, in reality, it was not possible to draw a true diagram of an atom. However, Peter presented atomic models to students as factual models that had a one-to-one correspondence with the reality of an atom. He failed to emphasise the historical context of the development of these atomic models and to describe their inaccuracy and tentativeness in terms of more contemporary theories of atomic structure:

Just to try and further clarify atoms. We looked at ‘Energy in the Home’, the first unit we looked at. Atoms can be divided into two, the nucleus which contains protons and neutrons, and the electrons in the outer. They're the ones which move around. They're the negatively charged ones. [Draws a diagram of an atom on the board. (see Figure 6)] So if you'd like to label that atom there as I have done.

Figure 6  Peter's chalkboard diagram of an atom

(Classroom Discourse & Field notes, 22 June 1992, p. 5)
Peter's language in this segment implies that his model of the atom is factual, which is a foundationist perspective of epistemology, and that the model represents the true structure of the atom which is a naive realist perspective on ontology. Therefore, this extract from the classroom discourse of Peter's Year 9 science class, provides further evidence of Peter's naive realism and also his foundationist philosophy on the status of scientific knowledge.

Peter used role play in order to involve students in modelling to the rest of the class the structure of solids, liquids, and gases. Each student participating in the role play was expected to portray the behaviour of a particle in a solid, a liquid, and a gas. Role play and diagrams of model atoms were used by Peter to give concrete existence to theoretical entities which could not be directly observed. Peter used also an analogy model of tearing a page of paper into smaller and smaller pieces in order to explain the concept of an element. These analogies were used to emphasise the structural features of atomic models in order to help explain structural features of the theoretical entity.

Peter's support of out-dated models which he presented as factual descriptions of theoretical entities, particularly his description of atomic structure, is characteristic of naive realism. His assumption that structural features of the model are representative of the structural features of the theoretical entity is further evidence of Peter's acceptance of naive realism. Although, examination of atomic theory presented Peter with the opportunity to discuss the tentativeness of scientific knowledge, he did not avail himself of the opportunity. Instead he presented out-dated diagrams of atoms as objective fact.

**Inadequate Scientific Knowledge**

Peter's inadequate knowledge of science, which he admitted in an interview, is evidenced by extracts of his classroom discourse. The following statements present serious misrepresentations of modern scientific explanations of natural phenomena:

Respiration is that process in which energy is burnt.

(Classroom Discourse, 8 April 1992, p.1)
Food in this battery is made up of chemicals.
(Classroom Discourse, 1 April 1992, p. 5)

Sugar or nutrients are needed by cells to respire.
(Classroom Discourse, 7 April 1992, p.4)

An element is in its simplest form.
(Classroom Discourse, 24 June 1992, p.1)

We've got zinc and sulfur. Upon a chemical reaction we get zinc sulfate which is the compound. So we've got two elements when we chemically combine them we get a compound being zinc sulfate.
(Classroom Discourse, 24 June 1992, p.3)

Although Peter's inadequate scientific knowledge is cause for concern, all teachers are likely to provide students with explanations that are not wholly scientifically accurate. However, of greater concern in the case of Peter's practice, was his unwillingness to admit his inadequate scientific knowledge in the face of student questioning of the validity of his statements about science. For example, in the face of student questioning, he maintained that 'made up of cells' did not define a living thing, that humans did not breathe out nitrogen, and that a bar graph should have vertical instead of horizontal bars. Peter's tendency to maintain that his statements about an aspect of scientific knowledge were the only correct statements which could be made reinforced inaccurate conceptions of the nature of scientific knowledge.

Relevancy

It is clear from the data that Peter was concerned about making science relevant to students. He directed students to focus on personal experiences such as daily diet, living for 12 hours on a handful of rice, and the operation of a dynamo on a bicycle, in order to provide meaningful and relevant data for classroom activities. For example, Peter instructed students to classify as solids, liquids, and gases all the components of their personal daily diet [regardless of the scientific accuracy of such an effort].

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Peter did not allow the application of relevancy to interfere with the presentation of scientific knowledge as facts or to influence his teacher-centred approach to teaching. As a consequence, the use of relevancy was peripheral to the presentation of the content of the lesson.

When Peter was asked if the reason that he organised snorkelling trips for students was to highlight the sorts of activities in which science could involve students (Interview, 24 June 1992), he indicated that such an aim was not his main purpose. Rather, he organised the snorkelling mainly as a fun activity to make the unit more interesting to students. The implication of Peter's pedagogical rationale is that he believed that science, as a subject, was not inherently interesting and, therefore, it required 'fun' activities.

Summary

A problem with Peter's Year 9 science lessons was that they often seemed to be disjointed. This was, at least in part, due to the conflict between Peter's poorly articulated view of how science developed as discovery and his implicit beliefs in objectivism, foundationalism, and theory building as an accumulation of facts. Peter's reliance on student workbooks reinforced these beliefs about the nature of science.

Although Peter aspired to the role of teacher as facilitator, his actual classroom roles of teacher as controller and teacher as source of scientific knowledge signify his belief in the need for teacher-centred instructional approaches and his naive realist, objectivist, and foundationist beliefs about the nature of science. Although Peter was aware of the inadequacy of his understanding of scientific knowledge, he was not aware of the extent of the inadequacy. He relied on the authority of scientists or the student workbook to give credence to the scientific knowledge that he attempted to explain to students.

Analysis of data obtained from observations of Peter's classroom practice and his audio recorded interviews provide evidence for the assertion that Peter's personal philosophy was underpinned by a naive realist ontology,
a conception of science as an accumulation of facts, and belief in the existence of objective, secure, and proven scientific knowledge.

SUMMARY OF THE CHAPTER

The results of the three case studies indicate striking similarities amongst the three teachers' personal philosophies of science. The relationship between Frank's, Greg's, and Peter's personal philosophies of science and philosophical theories can be shown by using the model from Chapter Two (see Figure 7).

Figure 7 Placement of Frank, Greg, and Peter on the philosophical model
Figure 7 indicates that the teachers are sited in one segment of the 'pie' of philosophical theories. The model highlights each teachers' ascription to: (1) absolutist notions of theory building, (2) objectivist and foundationist epistemologies, and (3) naive realist ontology. The model illustrates the consistency amongst the three teachers' beliefs about the nature of science.

For Frank, Greg, and Peter, scientific observations corresponded to reality. This belief in correspondence is the cornerstone of naive realism. Use of the journey metaphor by both Greg and Frank signified their objectivist epistemologies, and use of the metaphors of teacher as controller and teacher as source of scientific knowledge by both Peter and Greg signified their objectivism. Peter's claims that he viewed his teaching role as teacher as facilitator and that his metaphor for science was science as discovery were not consistent with his teacher-centred instructional approach. The teacher-centredness of the teaching practice of the three teachers was consistent with their beliefs in objectivism and their acceptance of naive realism.

Although Greg discussed the tentativeness of scientific knowledge with students, his language implied generally a foundationist perspective on the security of scientific knowledge. Peter and Frank had similar foundationist perspectives. Although the three teachers ascribed to absolutist notions of theory building, some differences emerged between the beliefs of Frank and Greg, on the one hand, and Peter, on the other. For example, Peter's beliefs about theory building were: (1) that science is an accumulation of facts; and (2) that the legitimacy of these facts and theories is attributable to their support by authority figures such as scientists or the text book. Peter's beliefs about theory building and his beliefs about epistemology and ontology are consistent with an inductive-empiricist philosophy of science.

For Frank, theories emerge as they 'percolate up' from observations which are made during practical activities. Frank's belief that theories evolve in this way is consistent with a positivistic philosophy of theory building, and his epistemological and ontological beliefs are consistent with a positivistic philosophy of science.
Chapter Four

According to Greg, scientific laws are pre-eminent in theory building. This belief explained Greg’s emphasis in his Year 10 science class on empirical approaches to obtaining confirming evidence for scientific laws. Greg’s emphasis on scientific laws, which he believed were verifiable empirically, is indicative also of a positivistic philosophy of science.

Both Frank and Greg held well-established personal philosophies of science which they presented in a coherent and articulate manner. However, there was some conflict between Greg’s explicit statements about the tentative status of scientific knowledge and his implicit belief in the security of knowledge. The lack of coherence in Peter’s personal philosophy of science might explain why order in Peter’s class often was established by recourse to the student workbooks. It seemed that his personal philosophy of science corresponded to the philosophy of science that was presented in the student workbooks.

As experienced teachers, Frank and Greg had had time to reflect on their philosophies of science. This reflectiveness had contributed to their abilities to present their beliefs about the nature of science in a highly articulate manner. Their personal philosophies of science formed a network of ontological, epistemological, and theory building beliefs that were consistent. Frank believed in the value of practical work to science education and, within that framework, he was willing to experiment on different instructional approaches to teaching science that might make science more relevant and interesting to students.

The three teachers in this study believed in the value of using personal experiences to make science more relevant to students. However, Peter tended to make more use of students’ personal experiences than did either Greg or Frank who tended to make more use of their own personal experiences. The evidence indicates that, from a constructivist perspective, Peter had superior pedagogical skills. However, his scientific knowledge was inadequate.

In all three cases, it was evident that the curriculum exerted strong control over the teachers’ classroom presentations of science to their students. Nevertheless, within the context of the extant curriculum, the lessons of
all three teachers were structured and organised in accordance with their personal philosophies of science. The design of the classroom laboratories assisted their teacher-centred approaches. The laboratories had a definite focus towards the side of the room where the demonstration bench was situated, and students sat in long rows facing this bench. At Lakatos High, the lack of a whiteboard behind the demonstration bench caused Peter to use frequently overhead transparencies, and caused Frank to use a mobile whiteboard. Both of these resources maintained student focus in one direction and helped to promote teacher-centred practice.

Extensive data obtained from classroom discourse, interviews, and field notes provided evidence that teachers' personal philosophies of science can have a profound effect on teaching practice, and, subsequently, on the classroom environment. In the next chapter, implications of the results of the data analyses are assessed.
CHAPTER FIVE

TEACHER PERSONAL PHILOSOPHIES OF SCIENCE AND
TEACHING PRACTICE

INTRODUCTION

This chapter presents a synthesis of the assertions of Chapter Four that are associated with case studies of three teachers of high school science. The synthesis takes the form of three general assertions and a discussion of evidence presented in Chapter Four which warrants them. The fourth and fifth sections of this chapter discuss the implications of this thesis for innovation and further study in science education.

THE NATURE OF ASSERTIONS

Assertions represent theory that emerges as a result of rigorous data collection and analysis within an interpretive research framework. The specific, or within-case, assertions presented in Chapter Four of this thesis emerged as a result of interpretive analyses of classroom discourse that were conducted in accordance with an interpretive approach to educational research (Erickson, 1986). These assertions are warranted by the evidence marshalled from the interpretive data, and theorise about the relationship between each teacher’s personal philosophy of science and their teaching practice. The analyses were conducted within an interpretive framework that is represented by Figure 1 (see Chapter Two).

In Chapter Five, general, or global, assertions are presented that are based on a synthesis of the specific assertions of Chapter Four. The general assertions theorise beyond the boundaries of this research study. Their focus is the relationships that might exist between beliefs about the nature of science of teachers of school science, in general, and their teaching practices. Erickson (1986) uses the term concrete universals to describe general assertions. 'Concrete' because these assertions are based on a detailed investigation of specific cases, and 'universal' because they have applicability to other cases. According to Erickson (1986), the
generalisability of interpretive research is enhanced by the generation of concrete universals.

In this thesis, the general assertions represent the concrete universals of the study. As such, they present tentative theory whose external validity can be determined only by cross-case analyses conducted in other contexts by educational researchers.

**GENERAL ASSERTION ONE**

*Experienced teachers' personal philosophies of science comprise well-established and strongly integrated networks of ontological, epistemological and theory building beliefs based on the traditional philosophies of science of inductive-empiricism and positivism.*

The assertions presented in Chapter Four identify specific features of each participant teacher's personal philosophy of science. The claim of General Assertion One, that teacher beliefs about the nature of science constitute a consistent and coherent network of ontological, epistemological and theory building beliefs, is discussed in greater detail in this section. In this study, teachers' ontological and epistemological beliefs were found to be strongly associated with the philosophical theories of *naïve realism*, *foundationism*, and *objectivism*, and their theory building beliefs were found to be associated strongly with *absolutist* philosophical theories characteristic of inductive-empiricist and positivist philosophies of science.

**Ontological Beliefs**

In this study, implicit belief in a one-to-one correspondence between observations of phenomena and physical reality, an ontology called *naïve realism*, was a general feature of teacher-initiated discussions about the value of students' observations in practical activities conducted during lesson time. Amongst the three teachers, naïve realist beliefs resulted in teachers' assumptions that students' observations of natural phenomena were not influenced by their beliefs. As a consequence, the three teachers believed that students performed theory-free observations during
practical activities. Such a belief is characteristic of both inductive-empiricist and positivist notions of the relationship between observations and reality.

Epistemological Beliefs

Science was presented by the three teachers as secure facts with almost no classroom discussion of how specific scientific knowledge developed. This type of presentation implies that the scientific facts are true indubitably and have always been true. The implicit acceptance by the three teachers of the apparently unchanging nature of scientific facts signifies a foundationist perspective on scientific knowledge security.

For example, Greg mentioned to students that laws had been found to be correct hundreds of years ago and that they continued to be correct. There was no discussion in Greg's class of how the relationships between observations and scientific laws were conceived initially. Instead, Greg presented the laws to students as though the laws had emerged fully formed. This practice implies that scientific knowledge is secure and unchanging over time, and represents a foundationist epistemology.

An important example that evidenced Frank's foundationist beliefs was observed when he presented, as a fact, the relationship between vascular systems, multicellularity, and terrestrial environments, and implied that this scientific knowledge always had existed in this form. Peter presented scientific knowledge in a manner similar to Frank's, as though scientific knowledge always had existed in the manner that he presented it. Occasionally, he referred also to authority figures, such as scientists, to provide additional authority to the scientific facts.

Greg was the only teacher to discuss with his students the tentativeness of scientific knowledge. This practice might signify a non-foundationist perspective which is supported by contemporary philosophers of science. However, Greg's explicit statements about the tentativeness of scientific knowledge conflicted with his implicit and prevalent notion that scientific knowledge was secure and had existed for hundreds of years in the forms in which he presented the knowledge to his Year 10 students.
In this study, analyses of classroom discourse indicated also that teachers supported implicitly the epistemological theory of objectivism. For these teachers, scientific knowledge was inherently objective to the extent that it possessed an existence that was independent of knowers. Consequently, scientific knowledge was regarded as having an independent existence in teachers' utterances, science textbooks, notes on the whiteboard and chalkboard, and in student workbooks.

Theory Building Beliefs

Analyses of classroom discourse indicated also that the three teachers involved in the study possessed similar theory building beliefs that were based on inductive-empiricist and positivist notions. Because theory building is related to the question of how scientific knowledge grows and develops, Peter's emphasis on the accumulation of scientific facts as being the way in which scientific knowledge grows is congruent with inductive-empiricist conceptions of theory building.

Frank's belief that theories emerged, or 'percolated up', from observations is indicative of positivistic notions of theory building. This belief caused him to emphasise continuously and exclusively to his students the importance of making careful observations. Greg's support of empirical verification of scientific laws as the basis of theory building also is indicative of a positivist philosophy. His promotion of student practical activities which were designed to confirm scientific laws is further evidence of Greg's positivist conception of theory building.

According to a philosophical scheme developed by Nadeau and Désautels (1984), Frank's personal philosophy of science, which was underpinned by a belief that scientific knowledge derives directly from observation of phenomena, is typical of a category of scientific belief called blissful empiricism. Greg's personal philosophy of science, which was underpinned by a belief that experimentation makes possible the verification of hypotheses, may be described as credulous experimentalism by Nadeau and Désautels (1984).
For all teachers participating in the study, the science curriculum that was mandated by school and science faculty policy pre-determined the science topics that they were required to teach. However, Greg and Frank possessed the necessary teaching experience and scientific knowledge that enabled them to develop student activities which were not dependant solely on student workbooks. By contrast, Peter's inadequate scientific knowledge resulted in his reliance on student workbooks as the major teaching resource. His use of these workbooks reinforced his inductive-empiricist notion of the nature of science. Tobin, Rennie and Fraser (1990) indicate that teachers with limited scientific understanding emphasise scientific facts and completion of exercises in workbooks, and that this type of practice does not lead necessarily to student understanding of science.

The Coherence of Teachers' Personal Philosophies of Science

Both Frank and Greg believed strongly in their personal philosophies of science and did not perceive a need for change. They presented their personal philosophies of science in an articulate and relatively coherent manner. By contrast, Peter's inadequate understanding of science caused him to depend largely on both his personal life experiences and the student workbooks as the basis for developing his philosophy of science. Although Peter's classroom discussions of the nature of science were articulate, they lacked coherence and consistency.

For these teachers, contemporary philosophers of science have had little influence on their beliefs about the nature of science. Analysis of classroom discourse indicates that Frank's positivistic belief about the nature of science was very consistent with his explicit statements about science and his teaching practice. Although Greg's positivist personal philosophy of science was somewhat incoherent it was the most coherent and well-articulated of the three teachers, it caused him to misrepresent the essence of science to his students. According to Burbules and Linn (1991), positivism is a major barrier to effective science teaching.

Peter might have developed a more representative personal philosophy of science if his recently completed preservice teacher education program
had focussed more on interrelating science knowledge, pedagogy, and philosophy, rather than emphasising pedagogy alone. An integrated approach might have enabled Peter to develop a personal philosophy of science that provided him with a framework on which to site his teaching practice so that he was more consistent and more confident in his approach to science teaching.

In summary, Frank's and Greg's personal philosophies of science constituted strongly integrated networks of beliefs that comprised: a naive realist ontology, a foundationist and objectivist epistemology, and a positivist theory building belief. Peter's beliefs about the nature of science were much less consistent or coherent. His personal philosophy of science was based on notions of the nature of science that were presented in student workbooks and on his own naive notions of the nature of science. These influences shaped Peter's personal philosophy of science which comprised: a naive realist ontology, an objectivist and foundationist epistemology, and an inductive-empiricist notion.

The influence that these teachers' personal philosophies of science have on their teaching practice is discussed in the next assertion.

GENERAL ASSERTION TWO

The traditional beliefs about the nature of science that are held by high school science teachers underpin role-determining metaphors that give rise to teacher-centred instructional practices.

A notable feature of the teaching practice of the three teachers observed in this study was the prevalence of role-determining metaphors that gave rise to teacher-centred instructional practices. The following section discusses the relationship between teachers' personal philosophies of science and the development of these role-determining metaphors.

Teachers' Role-Determining Metaphors

The three teachers' beliefs in the objectivist and foundationist nature of scientific knowledge provided a framework that (1) reinforced their perceptions of the need for roles such as teacher as controller and teacher as
source of scientific knowledge, and (2) supported their views about the need to implement teacher-centred instruction.

The conception of scientific knowledge as secure, unchanging, and discrete, caused each of the three teachers to regard scientific knowledge as a commodity and to assume responsibility for making it available to students. As a consequence, role-determining metaphors such as teacher as controller and teacher as source of scientific knowledge prevailed. In these roles, the teachers perceived a need to control both the type of scientific knowledge presented in their school science classrooms and the type of classroom interaction that would enable them to 'deliver' the knowledge.

Foundationist and objectivist beliefs caused Greg and Frank to conceive of science as rugged terrain over which they, as pathfinders, led the teaching and learning journey. Their teacher as pathfinder roles gave rise to the teacher assuming responsibility for guiding students over the terrain without losing control of the journey, and ensuring that they remained on the curriculum 'content' path.

These teacher roles gave rise also to teacher-centred instructional practices in which the teachers initiated almost all classroom activity. All student practical work and student seat-work, and much of the whole-class interaction, was initiated and controlled by the teachers.

**Teachers' Theory Building Beliefs and Group Practical Work**

In particular, teachers' beliefs about theory building influenced their views about the conduct of student group practical work. In accordance with their teacher-centredness, the three teachers initiated all practical activities in the classroom. However, each teacher's theory building beliefs influenced the conduct of student activities in a particular manner.

For example, Frank required his Year 8 students to conduct practical activities in which the emphasis was on making theory-free observations. Although Frank rarely discussed scientific theories, he expected the students to develop the scientific theories from the observations that they conducted during practical activities in the classroom. Frank's emphasis on theory-free observations and the automatic emergence of scientific
theories from observation in student practical activities was congruent with his positivistic beliefs about theory building.

Greg's teaching of student practical activities was congruent also with his positivistic theory building beliefs. In his Year 10 class, students conducted practical activities in order to confirm scientific laws. In the conduct of these practical activities much emphasis was placed on observation. Greg believed that because he could observe the confirmation of scientific laws in nature, confirmation of scientific laws was an appropriate purpose for student practical activities in the classroom.

Peter's inductive-empiricist belief in theory building as an accumulation of facts explained the reduced significance of student practical activities in his Year 9 science class. In his teaching practice, Peter's strong emphasis on individual seat-work activities, such as students answering in their notebooks questions from the student workbook and students completing tables and diagrams in their notebooks, was consistent with his inductive-empiricist belief of theory building as an accumulation of facts.

Teachers' Beliefs and Student Prior Knowledge

Amongst the three teachers, the role-determining metaphors of the teacher as source of scientific knowledge and teacher as controller served as major epistemological referents, and caused the teachers to neglect students' prior knowledge and experience. Researchers (Clement, 1983; Driver & Bell, 1986; Gardner, 1984; McCloskey, 1983) argue that students enter classes with prior conceptions about a wide range of scientific knowledge as a result of their personal experiences. Consideration of student prior knowledge and experiences is one of the cornerstones of constructivist epistemology when it is applied to classroom situations (Driver & Bell, 1986). When students are not asked to contribute their prior understandings they might be denied opportunities to build on their extant knowledge. In their teaching practice, Greg and Frank rarely attempted to learn about the topic-related prior knowledge of their students.

In Greg's class, lack of consideration of students' prior learning experiences resulted in students repeating practical activities such as
determination of the volume of an irregular solid and use of a Cartesian Diver that they had completed in previous units of study. This led to an undercurrent of dissatisfaction amongst students. In Frank’s case, his lack of reference to students’ prior understandings caused him to make unwarranted assumptions about students’ understandings. Consequently, he set activities that assumed a greater level of student understanding than existed. This resulted often in students becoming confused about what they were expected to observe during practical activities. For example, his expectation that students would be able to identify transport cells in a stained cross-section of a plant stem when his students had no experience of identifying these cells, led to student confusion during the practical activity.

Peter used pedagogical techniques, such as brainstorming, word recognition, and student reading, in order to enhance the involvement of students in the teaching and learning process in the classroom. However, these instructional techniques were not designed to inform and influence the curriculum ‘content’ of the lesson or the teaching and learning practices. The specification of scientific knowledge in Peter’s Year 9 class was not influenced by his perception of students’ extant understandings.

In summary, the thesis highlights the strong relationship between teachers’ traditional beliefs about the nature of science and their teacher-centred classroom roles and teaching practice. The influence of other key factors in maintaining this relationship is discussed in General Assertion Three.

GENERAL ASSERTION THREE

The relationship between high school science teachers’ traditional beliefs about the nature of science and their teacher-centred teaching practices is reinforced by institutional factors such as curriculum policy, teaching resources, laboratory design and classroom organisation.

Researchers (Clark & Peterson, 1986; Shavelson & Stern, 1981) have argued that teacher practice is constrained not only by teacher beliefs but also by factors external to the teacher. These factors include the science
curriculum and school policy, resource availability, features of laboratory design and classroom organisation. In this study, influence of these factors on teachers' personal philosophies of science was examined.

Curriculum Policy and Teaching Resources

According to Duschl and Wright (1989), curriculum objectives have significant influence on teacher selection of instructional tasks. In this study, it was found that the curriculum policies influenced the type of science knowledge and, therefore, the nature of science that was taught by pre-specifying learning outcomes for each 10-week science curriculum unit of study. The learning outcomes were written as specific objectives which tended to emphasise propositional knowledge and skill development, and were expressed mostly by descriptors, such as 'recall', 'distinguish', 'state', 'tell', that imply low levels of intellectual activity. The use of learning outcome descriptors that emphasise the recall and statement of scientific facts implicitly supports an inductive-empiricist notion of the nature of science.

A number of years ago, the learning outcome statements were used by the science faculty at Lakatos High to develop science workbooks that were in use during this study. These workbooks prescribed student activities that were related directly to the pre-specified learning outcomes of the curriculum document. Both Peter and Frank used the student workbooks extensively. The workbooks reinforced also Peter's ingenuous belief in science as an accumulation of facts.

According to Gallagher (1991), inexperienced teachers can be influenced strongly by the presentation of science in text books. As discussed in Chapter Four, the types of resources that were used by the three science teachers were dependent on availability and were related directly to curriculum requirements. Students in Frank's Year 8 science class were issued with a science textbook that Frank used as a source of scientific facts. Although Greg used a range of resources, including video recordings and text books, his use of these resources was restricted to illustrating principles or laws that he had presented already to the class.
Laboratory Design and Classroom Organisation

The design of the school laboratories and the classroom organisation that was observed during this study promoted implicitly teacher-centred instructional approaches. For example, in Greg's classroom laboratory (see Figure 3 in Chapter Four) the laboratory design, which consisted of peripheral benches with student desks in the centre, directed student attention towards the chalk board and demonstration bench where Greg usually stood to deliver the lesson.

The classroom laboratories in which Peter's and Frank's science classes were conducted consisted also of a central demonstration bench, peripheral student benches and student desks in rows, in the middle of the laboratory. The teachers used various techniques to ensure that student attention often was focused in that direction. For example, Frank used a transportable whiteboard that he located at the side of the demonstration bench, and Peter used extensively the overhead projector which he positioned on the demonstration bench. Students' desks were arranged in rows so that all students sat facing the demonstration bench. The teachers delivered their lessons in close proximity to the demonstration bench. This organisational setting supported a teacher-centred instructional approach by reducing opportunities for student-student interaction and by helping to ensure that teacher control of nearly all aspects of the lesson was maintained.

Teachers who demonstrate contemporary personal philosophies of science might use other techniques to reduce the obvious teacher-centred orientation of traditional classroom laboratories. For example, they could alter their position in the classroom so that the 'front' and 'back' of the classroom were less well-defined. Rearranging student desks so that students sit in groups, rather than in rows, provides students with increased opportunities to interact with each other and discuss aspects of their scientific knowledge.

In summary, analyses of the features of the classroom environment discussed in this section highlight the influence of the curriculum in determining the type of scientific knowledge that was deemed
appropriate for students to learn. A curriculum policy which emphasised propositional scientific knowledge and basic laboratory skills, and which largely ignored other areas of scientific knowledge, reinforced the teachers' traditional inductive-empiricist or positivist beliefs about the nature of science.

Evidence suggests that the traditional philosophical notions of the nature of science which were implicit in the teaching resources used by the teachers reinforced their traditional beliefs and teacher-centred practices. Laboratory design and classroom organisation also reinforced teacher-centred classroom practices and implicitly reinforced teachers' traditional beliefs about the nature of science.

Evidence obtained in this study identifies the complex relationship between teachers' personal philosophies of science, their teaching practice, and key institutional factors related to the organisation of school science. The evidence indicates that teachers' traditional beliefs about the nature of science are strongly related to teacher-centred classroom roles and teaching practices, and that this relationship is reinforced by institutional factors associated with the curriculum policies and classroom design structures that shape school science.

**IMPLICATIONS FOR EDUCATIONAL INNOVATION**

This thesis presents evidence of the strong influence of teachers' personal philosophies of science on teaching practice in the science classroom and, consequently, on the classroom environment. These results are consistent with the claims of Robinson (1969) that teachers' classroom behaviour, pupil task selection, and selection of instructional materials are influenced by teachers' conceptions of the nature of science. These claims were echoed by Martin (1972) and are supported by the results of recent studies conducted by Brickhouse (1989, 1990) which indicate that teachers' views about the nature of science influence their classroom practice.

However, according to Duschl and Wright (1989), teachers' beliefs about the nature of science, particularly teachers' images about the role of scientific theories, do not influence significantly teachers' decisions about
instructional strategies. These researchers investigated the extent to which teachers considered the nature of the subject in their decisions about planning and teaching science, and found that other factors, such as the perceived developmental level of the students, the required learning outcomes of the particular science course, and teacher accountability, were most influential on teachers' selection of particular teaching practices. However, the results of the study reported in this thesis indicate that teachers' personal philosophies of science have a significant influence on teaching practice. This study found also that other key factors, such as the science curriculum, reinforce teachers' traditional inductive-empiricist and positivist beliefs and their teaching practices.

The results of this study have implications for the implementation of innovative science teaching practices that are informed by constructivism. The results indicate that if teachers' traditional inductive-empiricist and positivist beliefs are not addressed then innovative curriculum practices that are designed to engender conceptual change amongst students and involve students in the construction of scientific knowledge are unlikely to have a major effect on teachers or students. For teachers to implement teaching practices informed by constructivism they should hold beliefs about the nature of science that are congruent with contemporary conceptions of the nature of science. Constructivistic principles of epistemology are consonant with belief in scientific or critical realism, non-foundationism, and theory building based on the significance of scientific theories, rather than on facts or laws.

However, inductive-empiricist and positivist notions of the nature of science are very persistent (Garrison & Bentley, 1990). In order to change teaching practice and alter the focus of the classroom environment, it is necessary to change teachers' conceptions of the nature of science. Although researchers (Cleminson, 1990; Hawkins & Pea, 1987; Larochelle & Désautels, 1991; and Meichtry, 1992) recommend conceptual change theory as a method for changing students' conceptions of the nature of science, these changes should be attempted only if teachers, themselves, have undergone conceptual change so that their conceptions of the nature of science are more representative of contemporary views of science presented by scientists and philosophers of science. Conceptual change
theory might be applied to teachers to help them to reconstruct their traditional personal philosophies of science.

Attention needs to be directed also towards the established use which teachers make of laboratory design. Removal of the teacher's demonstration bench is likely to remove an artificial focus in the laboratory and obviate, therefore, the need for students to look up continuously at the teacher. This type of physical reorganisation might help to ensure that teacher-centredness is not reinforced implicitly by the architectural design of the laboratory. Other aspects of classroom reorganisation, such as placing tables in groups rather than in rows, also can provide students with greater opportunities to interact with each other during science lessons.

FURTHER RESEARCH

This study investigated the effect of teacher beliefs about the nature of science on teaching practice and classroom environment. A complementary future study that extends the focus of this study could involve a detailed investigation of the influence on students' beliefs about the nature of science of teachers' personal philosophies of science. Such a study would involve a focus on the development of students' beliefs about the nature and role of theory and observation in science.

Another area of study is suggested by the implications of conceptual change theory for the modification of teacher beliefs about the nature of science. It seems feasible to develop a model that engenders change in teachers' beliefs about the nature of science. Further research could focus on the implementation of the model in a collaborative research mode with a teacher or, preferably, a group of teachers in the same science faculty. The results of the process would be examined to assess the effectiveness of the model in achieving its aim. The model could be developed also for broader implementation in inservice teacher education programs. Once the model has been implemented, teaching practices that are more appropriate for application within a contemporary personal philosophy of science framework would be trialled and evaluated.
In this study, observations of classroom interactions, which provided the data for each case study, indicated the value of examining teachers' alternative frameworks with respect to their beliefs about the nature of science. Research on alternative frameworks (Johsua & Dupin, 1987; Solomon, 1983, 1987) indicates that in relation to particular scientific concepts many students apply a scientific framework in the classroom and an alternative 'common sense' framework when they are outside the classroom. The results of this study suggest that research that is designed to examine teachers' philosophical frameworks should establish the extent to which teachers' personal beliefs about the nature of science vary from the classroom context to other situations. Such a study might ask whether teachers use inductive-empiricist or positivist notions of the nature of science in the classroom largely because these notions are reinforced by factors such as teaching resources and laboratory design but, when they interact with their peers outside of the classroom context, do they apply more contemporary notions of the nature of science?

This thesis also raises the complementary question of who should determine what scientific knowledge is appropriate for the school science classroom?

These are some of the possible areas of further study that have arisen during the course of this study and the presentation of this thesis. The challenge is to involve teachers in modifying their traditional beliefs about the nature of science so that the philosophy of science which they present to their students more truthfully represents the practice of science and the development of scientific knowledge. If this can be achieved then teacher classroom practice also might be changed so that innovations in teaching practice, such as those based on constructivist epistemology, will have a better chance of being implemented and maintained in the long term.
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APPENDICES

Three appendices are presented in this section of the thesis. Appendix A is a verbatim transcript of an audio-tape recording of one of Greg's Year 10 science lessons. Appendix B is a copy of the field notes recorded by the participant-observer of the same lesson. During data analyses the transcript and field notes of each observed lesson were correlated in order to present a record of the classroom interaction that had occurred. Appendix A contains references to the field notes because field notes and transcripts were interrelated in order to make sense of the classroom interactions.

Appendix C is a verbatim transcript of Peter's interview that was based on the interview schedule that is presented in Table 4 of Chapter Three. The interview transcripts were used in conjunction with the classroom discourse transcripts and field notes.
APPENDIX A

TRANSCRIPT OF CLASSROOM DISCOURSE:
GREG’S LESSON OF 27/5/92

General classroom noise. 30secs.
T: [Listening]?? this way now please.
10secs.
T: What I’m going to do today is to [??] a few worksheets on some examples using calculations on work and different types of energy. We won’t be using these at all today. You won’t have to rely on the examples in your books. You can all work on doing these [the worksheets]. You can the ones in your book if you want to do extra stuff and I’ll show you each of the cartoon things 5.1 is on work and two types of energy - potential and kinetic. Ok So I’ll hand these out to give you something to do while I put the tape in. The ones on work are the problem set two and on the back should be problem set three which is potential energy. Just ignore that one. I’ll go through the typed example in a moment. [Student rustling] Right, everyone got the sheet? The type example is done for you but I’ll go through it. We established yesterday that work is force times distance. And the first example is 'What force is necessary to lift a twelve kilogram object five metres vertically?' [Teacher draws diagram of question on board.] Twelve kilograms and is lifted up five metres. And you have to work how much work has been done to do that. Well, work is equal to force times displacement. [Equation $W = F.s$ written on board] Now this thing is lifted vertically so the vertical height in this case so the [??] the force needed to lift it. Now to lift that object what is the force that you have to exert?The question doesn’t tell you what force the person has to exert. So what is the force? My father used to always talk about skyhooks. If you couldn’t figure out a way of lifting it use a skyhook. I never ever found out what a skyhook was. Something in his mind. It was this, if you couldn’t solve the problem you used a skyhook. In other words you couldn’t solve it. What’s going to lift this? [The object] What the force going to be used to lift this?
Sm: more than 120N.
T: Where did you get 120 from?
Sm: [difficult to decipher]120 grams.
T: Well what does the 120 Newtons, the value is approximately correct. What does that value represent?
Sm: That’s the force pulling it down Sir.
T: What’s the one word that replaces ‘the force pulling down’?
Ss: Gravity.
T: Better still. What’s another one better than that?
Sm: Weight.
T: The weight! The weight of the object. The force of gravity acting on that mass is weight. [ Writes on the board \( F = mg \) ] How do I calculate the weight given the mass? We've done it. The force of gravity acting on that mass. So what do I multiply it by?

Ss: 9.8

T: 9.8, the acceleration due to gravity. If I let the thing go that force of gravity would accelerate it down to earth and that acceleration is 9.8 m per second per second. So we use that. So weight in this case, [ writes on the board \( Wt. = mg \) ] weight is generally worked out by multiplying the mass by \( g \), small \( g \). There is a big \( G \) and it's another value altogether. So it's the mass times 9.8. Now that's the weight, we've done that. Now that force needed to lift that would be a force that is opposite in direction slightly more than that to lift it. If it was exactly the same it would stay there, it must be slightly more. It only has to be infinitasimly more to lift it. Just has to be slightly more to lift it, slightly larger to lift it.

Sm: Sir, the smaller it is, like just over the limit, the longer it would take to move it wouldn't it?

T: Yeah, but once you get, it only needs to be slightly larger as you start to move it. Once it's moving it's in a state of inertia and if the two are the same it will just go up at a constant velocity. If it stayed the same ah size on here it wouldn't, no, if it stayed slightly larger it would keep accelerating and then we're probably doing more work by doing that but the thing is, ignoring the starting force to get a thing moving [ that? ] suddenly started up and then moved up therefore the force required to lift it will be the exact opposite of the weight. So this force here [ uses board] is also equal to mg, needed to lift it. And so this force here we can look at here 12 multiplied by 9.8 [ demonstrates this calculation on the board ] Now the video uses 10 because it's asking you to do mental arithmetic and in the TE exams, the leaving exams you used to be allowed to use 10 before calculators were allowed to be taken in. Now that calculators can be taken in we go back to using 9.8. You don't need to approximate anymore you can do it exactly because a calculator all it means is pressing another button really. So, you calculate that or you can take that and substitute it straight back into here \[ W = F.s = 12 \times 9.8 \times 5 \] The work done is 12 multiplied by 9.8 multiplied by 5. Crunch those into your calculator and the answer should come out as Joules which are actually Newton-metres. OK that's what I call a two stage calculation. You have to calculate something first before you can calculate the work. So you have to calculate the force first acting on the object. You were only given its mass and you were given that it had been lifted up five metres You should have at the beginning of any exam paper, if you have to use \( g \), it will be given to you at the
Appendix A

beginning of the paper as a constant. You never have to remember it but I don't know of a person whose capable of passing a 6 4 test or a physics test who doesn't remember 9.8. They still put it on the exam paper. You aren't expected to remember it. OK, so you calculate the force first and you [thread??] that into the work formula, the work equation and you get the answer. While I'm cueing in this tape on work, I haven't shown the one on work have I?

Ss: No.

T: You may have seen it in lower school ah a couple of years ago but I want you to have a go at 2, 'What work is done when a force of 15newtons is used to slide a box 7metres across a floor?' That's a bit easier than the previous one. It's a one stage calculation. Put the information down the side. [writes information on board] Put the equation and then substitute.

[Sounds of students moving and some student talk. Teacher sets up video. 2min]

T: OK. This tape, the famous Eureka series. This ones on work. Just put your pens down please.

[Sound of video starting up]

VIDEO

Eureka
The story so far. Mass refers to how much stuff a thing contains. Weight refers to the rate at which that amount of stuff is being accelerated towards the earth. In other words weight is just another way of saying 'force of gravity'. An objects mass never varies but its weight can go up or down depending on the force of gravity acting on it in various parts of the universe. These barbells have a mass of 120kilograms. Since they are resting on the surface of the planet Earth, we know that the force of gravity acting on them is about 10 times that number of Newtons. It takes a very strong man to lift something that weighs so much because if the barbell is being pulled down by a force of 1200Newton. It must take 1200Newtons of force to hold it up. Of course if we were on the moon where the force of gravity is only 1/6 that of the earth anybody could do it but we're not on the moon. Umm, that looks like hard work but how much work? 1200Newtons work to lift the barbell? Umm, how far? Exactly 2metres. Umm, but wait if you only lifted the barbell half that distance, say 1metre surely that doesn't take as much work as lifting the barbell 2metres? When you lift the barbell all the way up you are doing 1200Newtons times 2metres worth of work. When you lift it only half way up you're doing half that
amount of work, 1200 Newtons times 1 metre, in fact this is how we measure work in physics. Work equals force times distance. Here you're doing 1200 Newton-metres of work and here you're doing 2400 Newton-metres of work. That's simple enough but suppose that after the show the strong man discovers that his car is stuck in the mud. He pushes it and pushes it but it won't budge a millimetre and suppose that at the very same time a clown who hasn't got a car is in the act of picking up the telephone to call a cab which of them would you say is doing work at this particular moment? The strong man or the clown? The clown because work equals force times distance. And although the telephone receiver only weighs about 2 Newtons while the strong man's car weighs perhaps 15000 Newtons, when he lifts the telephone receiver the clown is applying a force of 2 Newtons through a distance of 15 centimetres lets say or 1/2 a metre, and therefore he's doing 2 Newtons times 1/2 metre of work which is one Newton-metre of work. The strong man on the other hand may be exerting thousands of Newtons of force but since the car is not moving there is no distance involved and the poor man isn't doing any work at all. A force of even thousands of Newtons times zero distance equals zero work. Whereas a force of only 2 Newtons moving only 1/2 metre does equal some work, even if it's only one Newton-metre work. But it is a bit awkward to keep on talking about Newton-metres of work so physicists have burrowed the name of a famous British scientist, James Prescott Joule. As a measure of work, one joule is the amount of work done when one Newton of force is applied through a distance of one metre, that's to say, one Newton-metre equals one joule which can also be written like this 1 Nm = 1 J. The clown did one joule of work when he lifted the telephone receiver and the strong man did 2400 joules of work when he lifted the barbells but of course when he tries to move his car it's a different story. He does zero joules of work.

[Slight shuffling sounds as video is finished]

T: Ok, that um, bit of cartoon (?) fits in quite well. It doesn't matter how big the force that force has got to move something otherwise there's no work. If you look at it inside the system that's from an outside observer but if you look at the strong man himself he's actually moving muscles and bones even though he's not moving the object. So he is actually expending energy so I suppose he's doing work moving his arms and his legs. So strictly speaking he probably would be but in terms of doing work on the car he's doing nothing. So you really have to talk in terms of 'what you're doing the work on' This thing [refers to the question from the text] you're doing work on the 12 kg mass [diagram on the board]. Now just look at that [teacher writes on the board as he talks] ?? at the units as well and put that down [writes on board concurrently] One joule of work is done when one Newton
moves. One joule of work is done when one Newton moves its point of application one metre.

Now you're going to um learn, in the next few periods anyway, the joule is very transferable to any type of energy you're talking about I can talk in terms of heat energy. I can talk in terms of the energy equivalent of the food I eat and I can refer to it as joules. In fact, if you look up you're diet chart it will refer to, so many grams of this will have so many kilojoules which is just a thousand joules. So, a joule then of work is done when one Newton moves its point of application one metre and there are other definitions of it as well. That's the one which refersa to work. If I'm talking about kinetic energy joules, if I'm talking about moving then the joules in that are exactly equivalent to the joules of work. And that's about the beauty about this metric system which we've taken on, is that once we've established the units transferable to all the other branches of physics [pause] not the case when I was at school. For every little separate type of calculation we had a separate units and it got terribly confusing.

Right how are we going with some of these? Who's got an answer for number two?

Sm: ??

T: Pardon.

Sm: 105 Joules.

T: 105 joules. Hand up if you got 105 joules. Hand up if you didn't finish. What? What were you doing?

Sm: ??

T: Oh. Who's done number three? Only about half of you.
'A man sliding a box across the floor finds that he needs to do 24 joules of work to move the box 5m. What is the value of the friction force which acts? So this person is doing work on the box against friction. He's not lifting it. He's having to push it against friction. Now that doesn't matter that's still work. But this time you don't know the force. You know the work. So you start off again put all the information down the side [demonstrates on the board] You know the work, you know the distance but you don't know the force. You've got two, only one missing. You can still use that equation. [W = F.s]
You just have to rearrange it a bit. That's important for putting information down, you find out what's missing. What info you've got and what you've got missing. Carry on with that and finish the rest off for homework.
R: I don't want to ask you any difficult questions. I just wanted to ask you do you think it's important that you do these sorts of activities in science? [doing some problem using W= F.s] In the science that you're doing?
Sf1: In this science yeah.

R: Why do you think it's important?
Sf1: Cause you're finding out how things are move and what it takes.
Sf2: New things of discovery.

R: So what would you call these? [points to problems in textbook]
What name would you give to them?
Sf1: Calculations for finding work, I guess.
Sf2: Yeah, work.

R: So would you if you two were speaking would you say for your calculation about doing work is that what you'd say?
Sfx2: Yeah,yeah.

R: OK. So what are these calculations helping you to discover?
Sf: How to do things. I don't know. What was the question again?

R: What are these calculations helping you to discover?
Sf: To find out how much work you need to. How does that affect
Sf: What it takes to move.

R: Do you think, are these a really important part of the course that you're doing at the present time?
Sf: Yeah.
Sf: I think it is.
Sf: It involves a work and work equals energy and energy equals physics.
[They both chuckle]

R: So you do problems or calculations like this, what other things would you do in this course?
Sf: Finding what happens.
Sf2: Explaining how things happen.

R: Sorry what did you say?
Sf2: Why it happens.
Sf: What was the question again?

R: Um, apart from calculations what other things would you do in this course?
Sf: Finding why things happen and why they happen, things like that.
R: Did you get to choose this course or were you put in this course?
Sf: I ended up going into it.
Sf: No you see what happens, we have this systems[??] course. We have Pathway one, pathway 2, pathway 3, and each pathway have four units. You pick which pathway you want and in that pathway [???] for you it says what you can do in that year.

R: Oh right, so you'll be doing physics units for the whole year?
Sfs: No, no. [??] different units.
Sf: Like physics is what we call unit 6.3 and we did last term unit 6.2 which is biology unit and next term we'll be doing chemistry.

R: So did you choose ...
Sfs: Different units.

R: Right.
Sf1: They're already put on you just pick which pathway you want.
Sf2: And I went up a unit. I was in a lower unit and I went up to this unit. I was doing chemistry but I wanted to do physics so I came up a unit.

R: Right, I'm still lost I think.
Sf: You're still lost. [amusement]

R: So if you choose a pathway
Sf: Yeah.

R: that pathway is for the year or just
Sf: For the year, for the year but it's divided up into different quarters
Sf: Different units.

R: So there's four units and each unit lasts for ten weeks?
Sf: Four units in each pathway.

R: Right.
Sf: Each unit is for one term.

R: Right.
Sf: Every term you change units.

R: Right. So that means that you choose at the beginning of the year the
Sf: Yeah, yeah.

R: the pathway that you are going to do for the year?
Sf: Actually we choosing in this year, in term three for next year.
R: Right. So therefore you would have chosen the bio, do you have to choose a biology unit and a chemistry unit and a physics unit or can you...
Sf: Well it depends, in lower school they tell you what to do, like in upper school you can pick any subject you want, right, but in lower school what can I say, they can control it you don't have any choice in subjects and that.

R: Right.
Sf: They've already given you the units, right, all you have to pick is the pathway which is connected to the units.

R: Oh, I see so you can select easier or more difficult units within the pathway.
Sf: Yes.

R: But not here? Not in lower school?
Sf: Not really.
Sf2: You can choose the level of science you want..

R: Right, right.
Sf: The pathway is telling you is telling you the level.
Sf2: That's right. You can do the higher units, it just gets divided up into how smart you are. [amusement]

R: Right thankyou.

T: This leads quite nicely into the concept of potential energy. This object was lifted up and work was done on it. Now normally when you do one of those problems there, if you do work on the box by sliding it across the floor that work will be expressed in some way. Those joules of work will appear somewhere and you can measure them. What would they appear as? Sliding, friction, how's that work going to be expressed? What sort of energy form is it going to?

Sms: Heat and noise.

T: Heat and noise right. So the work done against friction there, the energy that I have expended doing that work will be changed to heat and in a lot of cases we can find the energy form that work will be expressed in. Work is done every time energy changes from one form to another. Now this here doesn't seem to be the case. If I lift that up to there that is not going to get hotter air is almost frictionless in this case. So obviously the energy got to be changed to one form or another. What is it changed to?

Sm: Potential energy.

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T: Right. What we call potential energy. Energy is stored in there. It's still in there. Whereas with the friction, the energy went out of the box and disappeared into space. Here [holds the box up] it's going to be stored. Now, the energy or the work done lifting that [using board] is the force times the distance. And we worked out that the force required to lift that was equal to its weight and that was \( m \cdot g \) so that becomes \( m \cdot g \cdot s \) [\( W = F \cdot s; \] \( W = mgs \)] and all that work is then stored in there as energy so we can just call that stored work, potential energy, because if we just roll it off the edge again and it hits the ground it then will be dissipated as heat. When a falling object hits something usually, unless it shifts a big mass of dirt, it'll be dissipated as heat. Now to end with that, I'm quite involved in archery at the moment I only use a fairly light bow it only pulls about 40 or 50 pounds whereas, they still do those in the old system, you can convert that to kilos by approximately halving it. The guy I went around with on the course last weekend he draws about a 90 pound, now when you pull his arrows out of the target and they go in that far, [uses his fingers to indicate about 10-15cm] when you pull them out, the tips are hot. They're quite hot and it's a cold day so when they go in all that energy which goes into heat, some of it goes into the target and some of it goes into the arrows, and so the work done by that arrow going into the target a little bit of it will be by spreading the material in the target which is usually cardboard and the rest is heat, the friction rubbing through. Here, all that work is going to be stored as potential energy. Now, if we don't talk in terms of displacement but in terms of height, and give it the symbol \( h \), we can substitute that \( s \) for \( mgh \), and now we have a method of calculating potential energy. All we do is calculate it as the amount of work we had to do in lifting up an object. So, this [\( W = mgh \); \( W = \text{potential energy}; \] \( W = E_p \)] and we give it the symbol big \( E \) subscript \( p \). That's the official symbol, big \( E \) subscript \( p \). And that's the potential energy. So potential energy, now I should emphasize that is gravitational potential energy. You have potential energy in dry cells, in stretched springs and so on. Lackey bands will have potential energy. In fact the potential energy of pulling apart an elastic band will be similar to that [gravitational potential energy] Force used to pull it back, distance, you know you've done work on that lackey band and the amount of work you've put into that lackey band is its potential energy. So the principle of working out the potential energy by the amount of work you've put into an object can apply to many things. And now the next set of problems at the back of the one on work, Set 3, we'll have to move fairly quickly because I'm only allowed, according to my program, to give you one period on work, one period on potential energy and one period on kinetic energy. And so we can't really do much justice in three hours to cover to those three. Physics 11 people would take them more than, you know, nearly two weeks.

Sm:
T: Do I use what?

Sm: In working out the equation do you use mg as 10 or 9.8?

T: 9.8. I said that earlier. Because we've got calculators use it as 9.8. If, oh here they've got 10, that's because this book, I photocopied this out of a book which was printed before calculators were generally available cheaply in schools. You people are born into a world that had calculators. I can remember saving up my spare pocket money to buy a calculator and all it could do was multiply, divide and subtract, the basics and if I went to the delux model it had a memory. One memory. Now for about a quarter of the cost that I paid for that one you can buy a you beaut scientific calculator. These, in those days, I'm talking about 1975, I paid about $45 dollars for the basic calculator and these were over $100. Now the value of the dollar then was also higher. Now when I was at University and had to do all these calculations, calculators just didn't exist. We had an old mechanical job we used to crank the wheel but we decided it was quicker to use your head. So, that's when 10 was used to make things a bit easier.

Sm: Do you reckon that when you were at school the kids learnt more because of that?

T: They learnt basic arithmatic skills better. Um if you go back one step further to my father who's an accountant and even the crude calculator didn't exist and he had to do, when he was checking other people's books, add them up and he had to add up pounds, shillings and pence, so instead of having two money columns, he had three, pounds shillings and pence. 12 pence to a shilling, 20 shillings to a pound and it wasn't all decimals and he could work out all three columns together in his head. That's only practice. When I left school I went into a bank. When I first went into the office I was taught how to balance the teller's book, I was allowed a little electric job which put out a cash registers strip. That was pretty good. I had three months of that then I had to go to bank training school for a month and I had to do the same thing but I wasn't allowed a calculator. we all freaked out

[some amused murmers from students]

Where's my adding machine, it wasn't a calculator, where's my adding machine? All we had to do was add up. By the end of the month we could add up quicker in our head than we could punch the keys on the keyboard. It's just practice. You can all add up. You all know up to your twelve times table but you're too lazy to use them aren't you because you've got a calculator. I fall into that trap to. No you're problem solving is probably not any better but your arithmatic skills are better.
Now arithmatic is just practice. It's like spelling. So does that answer your question?

Sm: Yeah.

T: What it does is frees you up to spend more time thinking about [a business] OK. I think they're a good thing but I think a lot of people reach for them even just to multiply 2 by 3.

[general student low level talk]

[slightly raised voice] Looking at number 1, the type example. [pause] What potential energy is gained by a bucket containing water of mass 20kg if it is raised two metres vertically?

[draws diagram of question on the board]

20kilos and it's raised two metres. Our information, mass equals 20, what is potential energy? What is potential energy gained? Everything on the surface of the earth even if it's sitting on the ground has potential energy because it's calculated with respect to the centre of the earth. That's where we consider gravity to be acting. OK. Simple proof of that is if you're sitting on the ground and you've got no potential energy because you're on the ground, because you've got no height why do you fall into a hole and break your leg? So you've still got energy because you can still fall into a hole and you can keep falling in until you get the the centre of the earth.

Sm: If we've got a equation where something is in Newtons do you have to convert it to kilograms or can you just leave it as Newtons?

T: If they're telling you what is a force. It has to be in Newtons.

Sm: No, it says a crate weighing, yeah, 490 Newtons. Question 4.

T: Well weight should be in Newtons. Now you stand on the bathroom scales and weight yourself in kilograms. Your not weighing yourself, you're actually finding out your mass. So you're using the wrong expression and if you want to find out your true weight basically you've got to multiply it by ten. So I'm 70 kilos, I weigh 70 multiplied by 9.8. 70 is my mass, approximately 700 is my weight. Potential energy then is equal to mgh [writes on the board $E_p = mgh$] and mass is 20, g is 9.8, [writes $E_p = 20 \times 9.8 \times 2$]and h is 2. You get a slightly different answer to your book there because they have used 10. So your value will be slightly below 400 and the answer will be in Joules. It's fairly basic. Your test consists of a few little problems like this. An example of a calculation of each of these. I guarantee that if you can work out all
these problems and you understand them you'll be able to answer every question on part B of the test. Let's say they're similar. OK, while you're working on number 2 of that we should have enough time to view the potential energy tape. This time it's David and Goliath.

R: Excuse me, can I ask you some questions on the work that you are doing at the present time?
Sm1: Yeah, I guess so.
Sm2: Suppose.

R: What would you describe this work as that you are doing at the present time?
Sm1: Fairly easy.
Sm3: Basic.

R: What word would you use to describe it apart from the fact that it's fairly easy?
Sm1: Simple mathematics.

R: Do you think that's important in the course that you're doing at the present time?
Sm1: Suppose so, Yeah.
Sm2: Yeah.
Sm3: It'll be used in the test.

R: Sorry.
Sm3: It'll be used in the test and other things.

R: It'll be used in the test. Is there any other reason why it's important, why you should be able to solve maths problems in a course like this?
Sm2: Because it's what the course outline is isn't it?
Sm3: Because it got a rule and rules are usually linked.
Sm2 and Sm3: Yeah.
Sm2: Because if you don't know how to add up you can't do any maths.
Sm3: You know the numbers and you know how to work it all out but you don't know which way it's going to be formed.
Sm2: Yeah.

[video on potential energy - similar format to video on work]

T: That's not stupid. That's good stuff. That's my favourite. The giant. Particularly when he's blowing a raspberry down the hole.

[background noise of student talk]
Appendix A

You've got five minutes left. How many people have finished set 3?
Finished set 3.

Sm: Yep.

T: Ah, I think you people could go early.

Ss: Yeah.

T: I will have a look at when you've finished. The people who have
finished may go early.

[sound of students packing up]
[teacher checks work]

T: Joules, joules, yep, yep.

T: How come you girls are still here?
Sf: Um.
Sf: We don't know how to do it.

T: You don't know how to do it. That's when you put your hand up
and ask. Basically substituting into the formula you've got which one?

Sf: Oh.

T: The answer I think is .5. Yeah, that's right.

Sm: Sir?

T: Right, it's pack up time now anyway. [students pack up] Look if you
don't know how to do this you'd better sort it out because they ???
they're just simple substitutions.
APPENDIX B

FIELD NOTES:
GREG'S LESSON OF 27/5/92

27/5/92  4210  Science - Physics

[Diagram with equations:
\[ F = mg \]
\[ W = F \cdot s \]
\[ S_m = 120 \text{ N} \]
\[ S_g - \text{gravity} \]
\[ S_m - \text{weight} \]

ON BOARD

Joule of work is done when
1 newton moves its point of application
1 m

\[ S_m = 105 \text{ J} \]
\[ s = 5m = h \]
\[ W = F \cdot s = mg \cdot s = mg \cdot h = \text{potential energy} = E_p \]

Slide book along Grant bench.

\[ s \text{: potential energy} \]

---

**No. 1 - Type example**

\[ m = 20 \text{ kg} \]
\[ h = 2m \]
\[ E_p = ? \]

\[ E_p = \text{work} = 20 \times 9.8 \times 2 \text{ J} \]

\[ \text{Joules} \]
While you're working on number 2 of that we should have enough time to show the potential energy video.

Videos shown on Work and Potential Energy.

Students answered questions from sheet. Left on bell.
APPENDIX C

PETER'S INTERVIEW: 8/4/92

"Transcript of interview of teacher of science. Qualifications - Diploma of Teaching (1990) upgrading to Bachelor of Education via external studies this year.
Second year of teaching (1992). Content areas of study - Biology and Human Biology. Currently teaching Years 8, 9 and 10.

R: I know that people feel a bit uncomfortable at times, talking about things but I just wanted to get some idea about how you think about things because it will help me put what you do in the classroom into perspective. For example, in terms of qualifications, what's your major area that you've studied?
P: Biological side, say Biol and Human Biol.

R: Oh yeah. And you teach?
P: Eights, Nines and Tens.

R: Right.
P: Lower school.

R: How would you define science?
P: Um, probably more of a discovery.

R: For the students?
P: For students yes, in which the teacher acts as a facilitator with regards to knowledge and also um giving students a direction to take. So the teachers not actually being a person who carries out the experiment or um, gives a lot of hints to it but a teacher who actually allows the students to discover for themselves how the operation of an experiment works or the operation of, what is going on.

R: Do you see that as your role? How would you describe your role in the classroom?
P: Ah, personally I would like to see a role as a why. You know why is this occurring? Why is this happening? After they've done the experiment or before you can bring into such things as the knowledge area, the knowledge part.

R: Do you think, do you view knowledge in science as being the most important aspect of science?
P: No I don't know.

R: What would you think would be?
P: I would say a lot of skills associated with science, the process skills would be as important as the knowledge. It's a difficult one that one because unless they've got the knowledge they won't know to do the experiment or to why is it occurring. A lot of emphasis I wouldn't place on knowledge in science.

R: How do you think students learn new ideas in science?
P: I'd say a lot of hands on material. Hands on situation. Pick up new ideas by experimenting um.

R: Where would the experiments come from? Like what would you use as a basis for the experiments? If you were introducing new ideas what would be the basis of those experiments?
P: Initially you'd have to get some of the concepts or terms across to them so they've got an idea of what they're actually talking about from there maybe lead on to the experimentation process.

R: I notice here for example that there have been booklets made up for each of the units do you see that as the basis for the units that you do? How do you view your role in terms of those booklets? Do you think the booklets are the important thing or do you have a feeling that that's the requirement in the school?
P: I think with um, regards to the student taking the booklets itself because it's theirs for that term they know that this is what we are going to do and so as a teacher it's helping you personally to say, 'Well let's turn to our next activity what we're dealing with,' because it's a sequential activities, because it's made, the actual booklet's made in correspondence with the tests enables the teacher if they use that book they know the students will have achieved the objectives of the unit plus do well in the test.

R: Where does the knowledge, you know you were talking about knowledge before experiments before, where do you think, where does the knowledge come from that the students get as they learn new ideas or in preparation for learning new ideas?
P: I would most likely say with a lot of teaching strategies that I use it would most likely come from myself.

R: So you don't depend on the textbook for example, to provide that knowledge?
P: See those textbooks, those books [school produced]don't really cater for a lot of knowledge. If you had a textbook such as the Fundamental Science textbooks. If students were issued with that therefore you could say look up your resource book which then they could use another skill such as um learning skills looking into a book.
R: So how do you know or if you've got knowledge and experimentation, that students are learning new ideas?
P: So really how do you know that they've actually learnt it?

R: How do you judge whether somethings been learnt or not?
P: That's probably where the method I use would be the interaction(?) in which you're talking about it. Get the students to talk what they've done, what they've actually experiment they've taken place and to get the ideas of what they're doing and that there enables me to think even if they know whatever's taken place has occurred therefore they've learnt something that they hadn't learnt previously.

R: Mmm, so by interaction you would judge whether they had learnt something or not? Learnt a new idea?
P: Cause it's easier for the teacher, yes. The interaction phase.

R: What role has the student in the learning process?
P: I'd like to see an active role that the student takes place therefore they're responding, they're asking and they're questioning, 'What is taking place? Why is it occurring?,' themselves.

R: Does that influence the sort of environment you try to
P: Yes most definately.

R: create in the. How would you describe that influence?
P: Um, the sort of environment in which questions from students are asked which leads on to um the knowledge part in which you're answering those questions and which they're hopefully retaining it.

R: How do you create the environment though where they feel, I mean do they come into your classroom ready to ask questions or do you do something to create an environment? Do you make a concious effort to create an environment where they feel they can ask questions or does it just happen?
P: No I don't think it just happens. I think um looking at the students themselves because they're a quiet, relatively quiet in terms of being isolated. If you pick on a student and say, Why is this occurring? If, students will never ask, the majority of students will not ask questions of teachers. So what I have to do to work around that is ask the students questions of which they might respond to it and hopefully it might lead other students to ask the why questions and thewhat.

R: So do you think that's the most important aspect of what you do to create the environment ion your classes.
P: I think it is an enjoyable one. [the environment]
R: It's just that I see from my observations you do other things that you use to create the environment in your class, for example, the use of humour in your class.
P: Yeah, but this is what I like whether it takes place or not I think. Reason that it hasn't taken place so far is because it's relatively new into the topic so it's new for them and I don't really want, you know, the what if questions will probably come towards the middle of the actual unit itself.

R: Mm.
P: Where they know a bit about the knowledge. They know a few of the terms that I'm talking about and from there they can grasp it all and then hopefully lead on to those sorts of questions.

R: What is the role of the test in these sort of units that you're doing with the Year 9s?
P: The role of the test. Well initially the test is a feedback to not only students but also teachers. If I give a student a test or not up to Year 8 and 9 I'd probably like to hang back on it because I really believe that all a test does is put students under pressure, it allows the good students always to succeed and allows the poor students who have maybe poor written skills and also poor retention skills to fail and all you're telling them is that they're a failure. Whereas if you had an assessment item which allowed for laboratory activities, allowed for assessment in areas apart from the test itself, the written test, it would encourage them to participate more in science and enhance their self-esteem. However, I think because of the restrictions through the SEA and the tertiary that it's, we have to build on, we have to get the students from Year 8, Year 9 and Year 10 to focus on a test and say once you get in Year 11 and 12 this is your expectations.

R: You've talked about how you see students learning new ideas in the classroom. How do you think, what's you view of how scientific ideas develop?
P: Um. I think, I think to answer that you really, the sort of question the teacher asks, if it's going to be a spatial question, which they can have you know creative ideas that'll allow for more scientific ideas to come through. If you've just got a what they classify as a close question in which it's a restricted answer I think that doesn't allow too much for scientific processes, scientific knowledge to expand with the students.

R: Mm, but if we just ignore the students for the present time, how do you think of scientific ideas developing in general? You know like um how do scientists develop new ideas?
P: The use of um activities?
R: Just in general terms how do you think scientific ideas develop?
P: I would say a lot of hands on situations.

R: Is there any, could you just expand on that for me a little bit?
P: Um, scientific such as um experiments, dealing with experiments, thinking of what's going on, what's going on in the process. What is the equipment that you are using? Why is it happening? From there it could lead on to um trying to gain information about that experiment so researching it and going into the knowledge side of it.

R: What about scientific theories? How do you think scientific theories develop?
P: [pause] Scientific theories.

R: Do you think the development of science or the way scientific ideas develop is important in teaching? Is that something that's important to teach in a classroom, in a science class? Is it important that students have an idea about the way science develops? I mean in general terms, out there?
P: I would say so but see because I've been restricted to where I've been. I haven't been out into industry so therefore it's really hard to answer that. I think if I was out in industry in which the scientific process took place and brought that info and that knowledge back into a classroom I think I could answer that but I can't really.

R: Do you have inside you though an idea, I mean, you have an idea about what science is?
P: Mm.

R: You teach in science
P: Yeah.

R: so you must have an idea about what you think science is
P: Yes.

R: so can you tell me what science is?
P: Ha, ha. Um, gee science is probably discovering new and, discovering new avenues and new ideas of how, of what the world is about and discovering information that people have already known about.

R: Do you mean by confirming what people already know about it?
P: Yes.

R: When you did your course, before you started teaching, did you do a lot of work on science in general or were the courses that you did very content
P: Yes, very content orientated. Very specific. All that we really focussed on was learning information that you would teach to year 11 and 12, for example, I focused on Biol and Human Biol so it was just. 'this is what you need to know for Human Biol, this is what you need to know for Biology.'

R: So was there much time spent on how scientific ideas develop or how theories develop?
P: No. The only areas they went into with Science was the um students' learning styles, teachers' teaching styles and there was nothing really on science itself as a general overview.

R: You've told me what you think science is, do you believe that your view of science influences the way you teach science in the classroom?
P: [pause] Mm. See I hadn't thought about that really. All I've thought of coming out of Uni. and saying, 'I'm a teacher,' is trying to effectively get across the information being taught in the, in your, objectives to the students in the best way that you can. And my whole idea is to make it fun. If I can incorporate fun and learning I've succeeded, I think, as a teacher.

R: So what is learning?
P: What is learning? Learning, what is learning?

R: So what do you mean by learning? Deep down what do you mean? You know what wuld you look for to say learning has taken place?
P: Learning. I'd say learning is the um grasping of information then knowledge or skills and using that in an everyday situation.

R: So does that mean that you believe that students learn things that are relevant or that they will use
P: I would say for students to learn effectively it would have to be relevant. Maybe not just for todays use but for future use.

R: Do you feel more confident talking about um the way you teach, I mean do you feel more confident talking about your approaches to teaching than you do about the content that you use at this stage? How long have you been teaching for?
P: This is my second year.

R: At the beginning of your second year of teaching.
P: Yes, and that's only part time. Last year I was taking two classes and this year I'm taking three.

R: So do you feel more confident talking about your approach to teaching than you do say about the content that you use or do you feel equally confident about both?
P: Um, I probably feel more confident about my approaches to teaching than the content.

R: Was that the emphasis which was placed on your course when you did it?
P: Most definitely. Most definitely. Content wasn't a big thing. It might've, I would say it would've been 25% of the course would have been content, 75% would have been the teaching itself.

R: Is that why you expressed to me the concern you have making sure that the content you use is. The concern that you have about content. Is that why you have that concern?
P: Most likely, yes.

R: What sorts of concerns do you have in that area?
P: For content? Such as too much information given,

R: Does that mean you're worried about sifting out the information you think is important or being sure that you present to the students material that you think is significant?
P: True. Yes. Um, making sure that the subject or the content that you're teaching them is valid to them at their age, the relevance of it. So in a lesson I'll try and relate information as much as possible to them and to their society that they're living in.

R: Are you concerned about accuracy? Is that important to you?
P: Yeah. Saying yes, I would like to see that I'm teaching the accurate information however, I know that I haven't been.

R: What makes you say that?
P: Um, not telling the wrong information but not being quite sure about whether the information has been totally accurate.

R: Does that concern you?
P: No it doesn't. [amusement from both]

R: Why not?
P: Depending on the situation, if I know that it's not that relevant to the whole idea it wouldn't worry me however, if um if I knew that it had to clarified or was important to them it would have to be positively identified as correct.

R: I don't have anything else I would like to ask you. Thanks very much P.
P: That's alright.