THE USE OF A METACOGNITIVE TOOL 
TO TRACK LEARNING 
IN SCIENCE BY ADULTS

by

PHILIP BRIMSON

Submitted for the Degree of Doctor of Philosophy

Department of Political, International & Policy Studies
School of Arts
University of Surrey

2009
ABSTRACT

The territory covered by this work includes the response to new information in science by adults.

A central aim is to shed some light on the problem of how new and more complex knowledge (specifically conceptual knowledge) develops or arises from old and less complex knowledge. This problem has challenged both philosophers and educators for over twenty centuries.

The study draws on perspectives from several academic disciplines, in particular from philosophy, science, and sociology, and to a lesser extent from psychology. These disciplines are used in the first part of the thesis to set the context, both for the problem and for the qualitative research approach which tackles it, as well as to review literature that pertains to the field. Among hindrances to learning that are considered, particular attention is given to difficulties encountered with science texts; trials of some experimental approaches to the problems are included.

The central research question concerns how adults learning science respond to new information, especially information that conflicts with their existing knowledge. The problem is approached within a constructivist framework using the metacognitive tool of the concept map as a means of tracking the type of learning (deep or surface) that is taking place. Data relating to the type of learning are also produced through questionnaires and interviews from volunteer participants who are pursuing further and higher education courses that include mandatory science components.

The results of the study indicate considerable reluctance to abandon what has been learned previously, in favour of new information. Contrary to expectation was the discovery that adults respond to new information with surface learning strategies, placing extensive reliance (initially at least) on memory, whether or not they declare a preference for meaningful learning. There are implications of this discovery for those who plan and deliver short ‘refresher’ training courses.
CONTENTS

Title

Abstract

Contents

Acknowledgements

Chapter 1. Introduction

Chapter 2. Knowledge and Methods of Acquiring It
   1. Introduction
   2. Review of knowledge and methods of knowing
   3. Summary

Chapter 3. The Learning Process
   1. Introduction
   2. Some issues relating to learning as conceptual change
   3. Barriers to learning
   4. Summary

Chapter 4. Adults Learning Science
   1. Introduction
   2. Adults learning
   3. Learning science
   4. Summary

Chapter 5. The Research Problem and Methods of Inquiry
   1. Introduction
   2. Identifying the research problem
   3. Tools
      a) Concept maps
      b) Questionnaire
      c) Interview
   4. Context for the field work
      a) FE college context
      b) The students
      c) Teacher as researcher
   5. Quality issues
      a) Sampling
      b) Ethical
      c) Validity & reliability
      d) Generalisability
      e) Interpretation
   6. Practical matters
      a) Choosing suitable topics
      b) Interview
      c) Time frame for field work
      d) Discussion relating to my empirical research
   7. Data analysis
   8. Summary
Chapter 6. **Results and Analysis**
   1. Introduction
   2. Results and analysis
   3. Summary

Chapter 7. **Discussion of Outcomes and Critique of the Work**
   1. Introduction
   2. Discussion and critique
   3. Summary

Chapter 8. **Conclusions**
   1. Introduction
   2. Assumptions
   3. Interpretation
   4. A wider context for the learning of science
   5. Contribution to knowledge and plans for further work

Appendices 1 - 9

Bibliography
TABLES


2. Comparison of Philosophic and Theological Knowledge with Natural Science

3. Characteristics of Spoke, Chain and net Style Concept Maps (after Kinchin et al 2000)

4. Indicators of Expertise in Concept Maps (from Kinchin 2000)
FIGURES

1. The Inductive-Deductive Nature of Science
2. Herschel's pattern of Discovery (Losee 1972)
3. Experiential Learning Cycle (Kolb)
5. Structure Diagrams Illustrating Geometric Isomers of 1,2 dichloroethene
7. Scoring Model for Concept Maps (redrawn, Novak & Gowin 1984)
8. Categories of Concept Maps (redrawn, Kinchin et al 2000)
10. Heidi's 1st Concept Map on Acids
11. Heidi's 2nd Concept Map on Acids - based on initial teaching
12. Heidi's 3rd Concept Map on Acids - incorporating extended knowledge
13. Jonathan's 1st Concept Map on Acids
14. Jonathan's 2nd Concept Map on Acids - based on Initial teaching
15. Jonathan's 3rd Concept Map on Acids - incorporating extended knowledge
16. Nathaniel's 1st Concept Map on Chemical Bonding and related properties
17. Nathaniel's 2nd Concept Map on Chemical Bonding and related properties - incorporating extended knowledge
18. Clare's 1st Concept Map on the Structure of Matter
19. Clare's 2nd Concept Map on the Structure of Matter - incorporating extended knowledge
20. Sally's Concept Map on The Structure of Matter
21. Penny's 1st Concept Map on the Structure of Matter
22. Penny's 2nd Concept Map on the structure of Matter  
   - incorporating extended knowledge

23. A re-drawing of Heidi's 2nd Concept Map (Figure 11)  
   showing addition of some cross-links
ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the infectious enthusiasm of Gill Nicholls in the early stages of this work. For more recent supervision, Rachel Brooks skilfully and gently led me away from some of the more excruciating absurdities of early drafts and gave invaluable advice regarding organisation of the material during the writing up process. Mark Olssen provided an overview that was always both refreshing and challenging. Dawn unstintingly gave critical support throughout and endured my distractions during the writing up with more grace than I had any right to expect. I am grateful to the Trustees of the Mercer Trust whose financial assistance made it possible for me to undertake the study; also to departmental staff and librarians of the University of Surrey for unfailing courtesy and assistance. The heroes of the work are my students, those intellectual adventurers whose willingness to abandon everything in pursuit of their dreams has been a source of both my admiration and inspiration.
CHAPTER 1
INTRODUCTION

The last third of a working life spent teaching science has been devoted almost entirely to students, most of whom were young adults in their early twenties, at both further and higher levels of education. The move from secondary education at a public school for girls to teaching those designated as ‘adults’ forced the need to review methods of teaching (mine) and learning (theirs). The curricula and methods of assessment were different, as well as the ages of the students, and a personal review was needed as the prelude to making a number of changes in both approach and organization.

Since my experience, gained through forty years of teaching science, will be used in this thesis as a viewpoint for surveying the contribution of other researchers in learning, it may be useful here to identify the context in which this experience was gained and, later (chapter 2), the views it helped to formulate.

I was appointed Assistant Master in a small (by today’s standards) public school for girls, at a time when the prosperity emerging from post-war reconstruction was forcing such institutions to acknowledge that conflicting ideals of women’s education were posing a challenge to the curriculum. Whilst those girls who, through character and grace, made significant contributions to sheltered boarding communities were still welcomed, and music and drama continued to ride high, provision of facilities and opportunities in science equal to those found in the boys’ schools was being demanded.
Parents, their daughters, and School Governors simply could not wait for resolution of debates about whether the ‘normal interests of the average girl’ should guide the construction of a syllabus in science, and whether botany should be replaced or supplemented by the inclusion of some instruction in animal biology. Inadequate (or non-existent) laboratory facilities and a shortage of women science teachers were preventing the growth of advanced work in science in girls schools, and so rapid solutions had to be found to these problems. Thus it was that I came to be the first male appointee to this school with its new laboratories. The brief given was that ‘Girls from this school to be reading science subjects at university within three years’. It was both a challenge to, and opportunity for, a young and energetic teacher, within an agreeable environment in the company of enthusiastic learners.

Two and a half decades later found me delivering courses containing science modules in the Art and Design and the Health and Social Care Departments of a College of Further Education which delivered Higher Education courses under the auspices of a West Country university. These were in addition to A-level and Access to Higher Education courses. The opportunities at this College for my continuing professional development (limited in the school) enabled me to have a platform for exploration of teaching/learning issues that were highlighted by my transfer from the School to the College. I completed a Bachelor of Arts degree in Education and Training (Plymouth University, part-time), and found that the dissonance between some of what I was reading and some of what I was observing in the classroom fostered ideas for this research work. It also enabled me to engage with more confidence in the seemingly interminable staff debates between those who argued that education
is a universal process that reflects a monolithic conception of human nature, and those who insisted that it must be culturally relevant to particular situations and societies. These debates on ideological issues seem to have been given a recent stimulus by James Callaghan’s speech on education, delivered at Ruskin College, Oxford, in October 1976, which inaugurated the ‘Great Debate’. The speech included a reference to science teaching which, in the view of the then Prime Minister, needed ‘a more technological bias’. An outcome of this debate was the consultative document *Alternatives for Science Education* (HMSO, 1979), and the resulting policy statement *Education through Science* (HMSO, 1981), which led to the formalising of a liaison between science and technology. But the problems were hardly concealed, and I recall attempts at reassurance given at the Annual Meeting of the Association for Science Education (ASE) in 1980 when Sir James Hamilton, then Permanent Secretary to the Department of Education and Science, said that, "nothing must be done to erode the understanding of fundamentals", and “an ill-taught course in technology was not to be preferred to a well-taught course in basic science” (Hamilton cited in Layton 1984, p 277). However, a change in the curriculum relationships of science and technology, from alternatives to uneasy partners, carried implications for the roles of each, and science teachers tended to regard the technology fraternity as cuckoos in the nest.

In 1980 a manifesto, signed by one hundred and forty two leading citizens, announced (‘The Times’ 27th February 1980) a new initiative of the Royal Society of Arts. Entitled ‘Education for Capability’, the manifesto expressed concern about the structure of British education and highlighted a view of the relationship between abstract knowledge and practical skill which the signatories saw as endemic to the British education system. The historical origin of this manifesto was, in part at least, the report of a policy committee headed by Lord Rothschild, the ‘Rothschild Report’ (1971), which argued that while basic research was concerned with an increase in
knowledge, useful research was directed to goals defined by others. Rothschild had a background in scientific research and supported the 'knowing' rather than 'doing' tradition so deplored by the 'Education for Capability' signatories. Today the external pressures towards short-term economic utility are greater than ever, but the most delicate and vulnerable section of the whole scientific enterprise remains in the education process, the training of future generations of scientists in the schools and universities (Mason 1991 p viii).

Efforts to modernise curricula and improve the teaching of science have been continuous and, in response to the Education for Sustainable Development Panel's final report, the Government produced the Department for Education and Science Sustainable Development Plan (DfES, 2003), which has as its first objective that all learners will develop the skills, knowledge, and value base to be active citizens in creating a more sustainable society. Since, as a society, we are still finding out what sustainable development means, educators have to focus on building a capacity to learn and adapt (Scott, 2003), knowing that the political, economic and cultural conditions under which learning occurs are changing rapidly.

In these circumstances it seems appropriate to reconsider some fundamental questions about what learning is and how it may best be monitored. My particular interest is in the learning of science by adults, and so the findings of my research work may, or may not, be applicable to young learners. The implications of the terms 'science' and 'adults' are explored in more detail in Chapter 4.

Adults will have spent much of their lives learning from experience and they are, therefore, likely to bring a more extensive biography to new situations than will younger learners. Their perceptions arise from experience and, in so far as they relate to science, are often based on misconceptions, for example, the direction of electron flow in an electric circuit, and so new information may well conflict with
existing perceptions. The research focuses on how adults respond to new information, and the tracking of that response. As a result of extensive study, Knowles (1970) became convinced that adults are more self-dependent, possess a greater reservoir of experience, are more ready to learn, and have a more problem-centred orientation to learning than do younger learners. But Knowles seemed to present a non-developmental view of adults – as though they are simply mature adolescents – and this did not accord with my observations in the classroom. It was clear that some new information encountered by adult learners on science programmes can conflict with their world view, for example, the need for preservatives in foods and cosmetics. Many adults have absorbed the message, or formed the view from advertisements, that preservatives are, at least, a potential source of harm. The risks from pathogenic organisms and natural biodegradation are generally beyond their horizons and so this new knowledge conflicts with views that are likely to be reinforced on a regular basis.

It was also clear that misconceptions and naïve views abound amongst many learners. For example, although Galileo asserted four hundred years ago that freely falling objects move with a constant acceleration that is independent of their mass, the prediction that heavier objects will descend more quickly than will lighter ones is very common among adults learning science, in my experience. It was also clear to me that views, such as the one given above, which had appeared to serve well in the past were not to be abandoned lightly, or were difficult to abandon – even in the face of apparently formidable evidence as to their limitations or incorrectness.

These observations, coupled with my dissatisfaction with the ‘explanations’ I found being given for the failure in assessment of some adults on science programmes, were the prompt for this study. The territory it covers includes the responses by adults to new information which may conflict with their world view when learning
science. A central issue concerns the problem of accounting for how new and more complex knowledge, specifically conceptual knowledge, develops or arises from old and less complex knowledge. The problem has been recognised over many centuries; according to Rouse (1956 p29-68), Plato in his dialogue *The Meno*, has Menon pressing Socrates on the issue of how one is able to leap ahead of what is known in the search for new understanding. Menon argues that understanding depends on prior learning, and when new knowledge is incompatible with this learning, one lacks a secure base on which to build. Two dozen centuries on, efforts to give a systematic account of knowledge, and especially scientific knowledge, serve to indicate that there is no consensus regarding the nature of methods of knowing, or tracking the responses of learners to new information which conflicts with their world view. This remains an area in which there is plenty of scope for further research, particularly where the learners are adults.

Classroom experience has demonstrated repeatedly the pertinence of Butterfield's (1968, p 1-2) observation that, it is "easy to teach anybody a new fact about Richelieu, but it needs light from heaven to enable a teacher to break the old framework in which the student has been accustomed to seeing his Richelieu". One of my aims is to understand a little more about this 'light from heaven', that is, to seek to understand the process by which learners are able to develop new knowledge that exceeds in complexity the knowledge they already possess. The apparent absence of headway in solving what is generally acknowledged to be the most challenging problem in understanding this process of learning – the so-called learning paradox, central to which is the ability to account for how new and more complex learning develops out of less complex learning, is justification enough for an attempt to make progress with it. The research I have undertaken focuses on tracking the process of cognitive change in adults learning science.

Mention has been made of the 'Great Debate' inaugurated in England and Wales
during the October of 1976. Nineteen years earlier, the American nation was jolted into questioning the quality of its science teachers and the science curriculum used in schools, by the launching of Sputnik 1 on 4th October 1957. This event is relevant since it changed the social and scientific climate of the America of the 1950's and 1960's. The new climate gave opportunity for the educational ideas of both Joseph Novak - who devised the concept map (the metacognitive tool used in my study), and David Ausubel - whose cognitive model is used in the interpretation of the data I produced.

Although theoretical approaches to learning can be traced back at least as far Descartes, experimental studies began when physiologists became interested in the operation of the senses and in measuring the speeds of simple motor responses. In 1879 the first laboratory for experimental psychology was established by Wilhelm Wundt at Leipzig, where one area of interest was the field of psychological and educational measurement known as psychophysics. The impact of the physical and biological sciences on psychology was accompanied by a paradigm shift from functionalism to behaviourism and this provided the impetus for an interest in learning to develop.

Behaviour theorists, from the early studies of Edward L. Thorndike at Columbia University, America and Ivan Pavlov at The Institute of Experimental Medicine St. Petersburgh, Russia, in the late nineteenth and early twentieth centuries through to the 1960s, developed theories of learning that attempted to explain all aspects of the learning process. Behaviourism focuses on the role of experience in governing behaviour and, according to Watson (1913 and cited by Mowrer and Klein 2001 p3), the more important determinants of our behaviour are learned. Traditionally, behaviours are considered to be learned through either classical (or respondent) conditioning where the response is elicited automatically and involuntarily, or by operant conditioning where the response is emitted voluntarily. A main goal of the
behaviourists was to determine the laws governing the learning process, and models to account for learned behaviour were put forward by Thorndike (Bower and Hilgard 1981), Hull (Hull 1943), Guthrie (1935, 1959) and Skinner (1938).

However, some limitations to these 'global learning theories' began to emerge by the 1950s, in particular, Tolman's (1959) perspective contrasted with the views of his contemporaries. Tolman did not see behaviour as reflecting an automatic response to an external stimulus, but rather that it has direction and purpose in terms of achieving an objective. His views rejecting the mechanistic viewpoint of the (now traditional) behaviourists took until the 1960's to gain acceptance. The transition from the wide ranging behaviourist learning theories to more specific contemporary cognitive theories occurred alongside the realisation that "our biological systems constrain what we do or do not learn about" (Mowrer and Klein 2001 p17) and, if they influence the process of learning, then they call into question the concept of general laws of learning.

Novak worked at Cornell University through the latter part of the twentieth century constructing a theory of education aimed at making learning more meaningful, and along the way he devised the concept map as a knowledge representation tool; this tool is used in my study to investigate how adults learning science respond to new information. Novak took on board the learning theory of Ausubel, which he saw as a powerful model of learning to guide education. Ausubel's assimilation theory of learning has been used extensively to underpin many science teacher education programmes in the UK over recent decades, and is appropriate to the approach of my study.

Evidence gathered in interviews from adults who participated in this study indicated that many of them thought they had not been well taught in science in secondary schools, with much emphasis placed on rote memorisation of complex data.
However, the nature of what is taught has changed, from an arena where the primary senses could detect those things that directly affect us, for example, Darwin observed flightless birds, to an arena where the things that affect us cannot be apprehended directly, for example, X-rays, and genes. In his 2007 Richard Dimbleby lecture for the BBC, the American science researcher Dr. J. Craig Venter quoted Dewey when he said that “in order to understand the world around them, children and adults need to learn to explore, challenge and problem solve”. My study looks at how adults respond to new information in science.

This study is about learning science and, inevitably, involves crossing traditional disciplinary boundaries. Thus, some appreciation of the features which are peculiar to science, including the methods by which it proceeds, are necessary in order to comprehend both the similarities and the differences between learning science and learning anything else. The context of the thesis is philosophical because I believe that philosophical methods and findings can be of use to educational theorists and teachers, just as they can be of use to scientists (and others, such as historians). A perception that philosophy is not so much a body of knowledge as an activity of criticism or clarification, and that all the sciences started as branches of philosophy, may be of use in helping the reader to understand this choice of context. Finally, the methods used in the study and the style of presentation of the analysis of the results, are very much those associated with the social sciences. Indeed, the thesis is submitted within the Faculty of Arts of this University and the qualitative approach it utilises is not so commonly associated with the physical sciences. But, this is not a study of science, it is a study about learning science, the approach chosen is considered the one with the greatest potential to be fruitful and helpful.

An argument that reappears in many guises, particularly since electronic aids for storage of, and access to, data have become widely available, advances the idea
that knowledge is somehow less important than the ability to retrieve it – 'we have
Google now'. Thus, it is unnecessary for children to learn basic historical or
geographical facts, and calculators make it unnecessary to be able to do elementary
arithmetic. More recently, it has been suggested (Financial Times 12.08.06) that
satellite navigation will render much of the knowledge of city taxi drivers nugatory.

My contention is that the development of theories or concepts, at anything other than
a trivial level, requires the possession of knowledge as a framework on which to
build. The suggestion that knowledge has no significance beyond isolated facts,
retrievable by means of a search engine such as Google, is, in my judgement, a view
which has implications that could be detrimental to our society.

This thesis is structured such that the three chapters which follow this introduction
serve both to give a review of literature relevant to the territory it covers, and to focus
on aspects of the subject matter which give a background to the study undertaken.
Thus, Chapter 2 considers both what counts as knowledge and how we come to
know what we know, particularly with reference to science. Chapter 3 looks at the
conceptualisation of knowledge and issues relating to learning as conceptual change,
and then considers some frequently encountered aspects relating to resistance (or
barriers) to learning, including problems with the comprehension of texts. Some
examples of problems I encountered with text comprehension, and the efforts I made
to address these are included here. Chapter 4 explores relevant aspects of the word
'adult', plus issues which – in my experience - relate particularly to the learning of
science. Chapter 5 discusses the research problem and all the theoretical and
practical matters which relate to the fieldwork. Chapter 6 contains the results of this
fieldwork together with an analysis of the findings. Chapter 7 comprises a discussion
of these findings plus a critique of the study, while Chapter 8 includes some general
remarks on assumptions and interpretative problems as well as setting the
conclusions reached in a wider context.
John Locke, in the introductory part of his 'Essay Concerning Human Understanding', known as the Epistle to the Reader and first published in 1690, identifies something of the intention of my thesis:

'It is ambition enough to be employed as an under-labourer in clearing the ground a little, and removing some of the rubbish which lies in the way to knowledge.'

CHAPTER 2

KNOWLEDGE and METHODS OF ACQUIRING IT

1. INTRODUCTION
While tradition offers us four sources of knowledge - the senses, memory, introspection and reason - a more contemporary list of alleged roads to knowledge, as given by Hospers (1967, p 122-141), includes sense-experience, reason, authority, intuition, revelation and faith. It is the first two items of Hospers’ list that will be explored in most detail, as they suggest a route by which new and more complex conceptual knowledge arises from less complex knowledge. This chapter examines that route, as context to the study I have made, the results providing some answers to questions about the ways in which adults learning science respond to new information. But first it is necessary to say something about what counts as knowledge and, in particular, scientific knowledge, and the way in which a philosophy of knowledge has influenced the teaching of science.

2. REVIEW OF KNOWLEDGE AND METHODS OF KNOWING IT
The history of epistemology shows that the nature of knowledge, its possibility and scope, has been of major interest to philosophers since it emerged as a subject for study. One of the main preoccupations has been the attempt to provide a general basis which would ensure the possibility of knowledge. The Greek Sceptics maintained that they were inquirers, refusing to acknowledge claims to knowledge unless a 'criterion of truth', as it was called, could be produced. The seventeenth and eighteenth centuries produced the Rationalists who emphasised the part played by reason, and the Empiricists who emphasised the part played by experience. The nineteenth century focused on induction in arriving at truths derived from experience, while the twentieth century brought the Logical Positivists who were great admirers of
the scientific method. Central to their doctrines is the principle of verifiability which, as expressed by Ayer (1971), claims that all statements are meaningful if they can be assessed either by an appeal to some foundational form of sense experience (synthetic or empirical truths), or by an appeal to the meanings of the words that constitute them (analytic truths). With all these attempts to define knowledge proving more or less unsatisfactory, today we tend to settle for something along the lines that it is belief that is both justified and true. The legitimation of knowledge owes credibility to three traditions: rationalism, for example, in mathematics where a conclusion rests on its own argument; to empiricism, for example, in science where sensory experience is the arbiter; and to pragmatism, a 'suck it and see' approach – which may have only a limited reliance on an underlying empirical reality.

Social theories of knowledge, whether post modernist or not, which make explicit its social and historical character, have dominated recent times, with educational research often caught in the tension between competing views of the social sciences. The 'traditional' approach - that there are natural and universal laws regulating and determining individual and social behaviour, and the more contemporary approach that emphasises individuality, where people are the initiators of their own actions and creators of their environment. These competing views make an appearance in the physical sciences as well and, interestingly, Plato in his Republic (Lee 1955) talks of an astronomer who wants to explore the laws which govern the motion of heavenly bodies. The naïve view is that first of all he should make the most precise observations. But, argues Plato, the actual motions of stars and planets are contaminated, because the physical reality is only an imperfect image of the ideas which are the true carriers of truth. He uses the example of a highly skilled Athenian engraver who could engrave in a metal plate the finest triangle one could imagine. But would anyone be foolish enough to make measurements on this triangle when, in actual fact, the principles of geometry establish these relations.
beyond any shadow of a doubt? Hence he comes to the conclusion that the true astronomer would not look up to heaven in his attempt to come to grips with the true laws of planetary motion, he would look down in deep contemplation, and thus find something which is eternal and unmarred by accidental distortions. Einstein was shocked into accepting Platonism and the possibility that experiments may give us only the tip of the iceberg, putting in jeopardy the very foundation of physics - the primacy of experimental evidence. The problem of wondering whether we can reconstruct the shape and extension of the submerged part by drawing conclusions from the tip which is at our disposal, is the very same problem facing the social scientist who wants to generalize from a small sample. The issue of generalisation is considered in greater depth in Chapter 5 of this thesis.

As explained in the introduction to this chapter, we source our knowledge from one or more frameworks or belief systems. These belief systems, while they may not be capable of providing answers to questions that can be subjected to proof, act as vehicles of understanding that can contribute insight into problems. Two such (mutually exclusive) frameworks within which inquiry can proceed are known as Patton’s ‘competing inquiry paradigms’ (Patton 1980, p 37): firstly, logical positivism, which uses quantitative and experimental methods to test hypothetical deductive generalisations. This paradigm was at its most influential during the eighteenth and nineteenth centuries, and was vindicated by the scientific discoveries made during that period - it was so firmly established as to be often described in the literature as ‘conventional beliefs’. The second paradigm, phenomenological inquiry, uses "qualitative and naturalistic processes to inductively and holistically understand human experience in context specific settings" (Patton 1980, p 37). This has come to be known as the constructivist - or interpretive paradigm.
The fundamental features of these two paradigms are contrasted in the table below:

Table 1

<table>
<thead>
<tr>
<th>CONVENTIONAL BELIEFS*</th>
<th>CONSTRUCTIVIST BELIEFS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ontology</strong></td>
<td></td>
</tr>
<tr>
<td>A REALIST ONTOLOGY asserts that there exists a single reality that is independent of any observer's interest in it and which operates according to immutable natural laws, many of which take cause-effect form. Truth is defined as that set of statements that is isomorphic to reality.</td>
<td>A RELATIVIST ONTOLOGY asserts that there exist multiple, socially constructed realities ungoverned by any natural laws, causal or otherwise. “Truth” is defined as the best informed (amount and quality of information) and most sophisticated (power with which the information is understood and used) construction on which there is consensus (although there may be several constructions extant that simultaneously meet that criterion).</td>
</tr>
<tr>
<td><strong>Epistemology</strong></td>
<td></td>
</tr>
<tr>
<td>A DUALIST OBJECTIVIST EPISTEMOLOGY asserts that it is possible (indeed mandatory) for an observer to exteriorize the phenomenon studied, remaining detached and distant from it (a state often called “subject-object dualism”), and excluding any value considerations from influencing it.</td>
<td>A MONISTIC SUBJECTIVIST EPISTEMOLOGY asserts that an inquirer and the inquired-into are interlocked in such a way that the findings of an investigation are the literal creation of the inquiry process. Note that this posture effectively destroys the classical ontology-epistemology distinction.</td>
</tr>
<tr>
<td><strong>Methodology</strong></td>
<td></td>
</tr>
<tr>
<td>AN INTERVENTIONIST METHODOLOGY strips context of its contaminating (confounding) influences (variables) so that the inquiry can converge on truth and explain nature as it really is and really works, leading to the capability to predict and to control.</td>
<td>A HERMENEUTIC METHODOLOGY involves a continuing dialectic of iteration, analysis, critique, reiteration, reanalysis and so on, leading to the emergence of a joint (among all the inquirers and respondents, or among etic and emic views) construction of a case.</td>
</tr>
</tbody>
</table>

*Note: in the twenty years since Lincoln & Guba published this table, attitudes have changed such that it would probably be true to say that constructivist beliefs have become the ‘conventional’ and what were formerly regarded as ‘conventional’ would be likely to be labelled ‘traditional’ or ‘modernist’.

As the summary table illustrates, the traditional objectivist approach takes a more deterministic view of human nature, and is positivist in its epistemology; the contemporary, subjectivist approach has its ontological roots in nominalism and is
decidedly anti-positivist, namely, viewing knowledge as personal, subjective and unique to the individual. The subjective approach more comfortably accommodates the constructivist approaches to learning that currently predominate in educational theory (Matthews, 1998, Phillips, 1995), and is generally considered well suited to qualitative investigations. Further, although my investigation is about the learning of science, it is not the science itself that is under investigation - I want to track whether a person has learned something rather than having merely learned to do something, so a qualitative approach is quite appropriate.

Moore & Young, (in Olssen 2004, p 251) draw attention to two opposing ideologies concerning the nature of knowledge: firstly, neo-conservative traditionalism, which asserts that there is a given body of knowledge which it is the responsibility of educational institutions to deliver. The experience of submitting to the discipline of the subject moulds a person into that kind of person whose characteristics are fairly predictable. As Scruton (1991) observed, this approach is not motivated by any epistemological concerns, but by the need to pass on the culture, the knowledge being an end in itself. Science education has been in this mould for over a century, and I was instructed in this framework. The science teacher who taught me chemistry at secondary school proudly, and frequently, declared that he was taught at university by a professor who had himself been a student of Ernest Rutherford - who had "discovered the atom" (sic). Knowledge was handed down to me as an inheritance - it was not something I should attempt to construct. The second, and opposing ideology, is technical instrumentalism, which challenges the neo-conservative view, and claims that knowledge is a means to an end - rather than an end in itself, and that it produces a particular kind of society, rather than being a maker of individuals. This view supported the development of vocational education but, since the publication of Sir Ron Dearing's review of qualifications for 16-19 year olds (Dearing 1996), the technical instrumentalists have infiltrated academic
education. A consequence of this is that teachers of science, as well as teachers of other subjects, are required to incorporate key skills to show how their subject links with other subjects and facilitates team work and communication.

The tension between these two ideologies remains unresolved, which suggests that there is need for debate to be focused on the question of knowledge. Moore and Young (2004) argue that the post-modernists make the claim that the neo-conservatives rely on arbitrary assumptions about knowledge. Yet they, in their turn, by arguing that knowledge cannot be separated from the method by which it is constructed, do nothing to pave the way towards a meaningful theory of knowledge.

Scheler (1980, p 76) makes an interesting contribution to the debate about what counts as knowledge by distinguishing between cultural knowledge (slow changing, for example, myths and religious knowledge), and artificial knowledge (fast changing and includes technological knowledge). Cultural knowledge used to be dominant, and education involved the teaching and learning of the culture so that it could be reproduced. This tended to result in 'a sameness' about individuals, and communities were based on those who conformed. Those who were different in any way were considered a potential or actual threat to those who were possessors of the cultural knowledge, namely, those who wielded power in the community, and had to be excluded – the heretics. Today, artificial knowledge is more dominant because it is more highly valued but, because it is swiftly changing, it does not have time to become embedded in the culture of a society.

The context chosen for this review of issues and ideas relevant to my study is essentially philosophical, but it is not the only context that is possible; for example, an historical or experiential framework might have been used. Each of these frameworks would impart a unique and legitimate perspective, and it will always be true that conclusions reached will be related to the chosen context. But the study is about the nature, scope and acquisition of knowledge and, traditionally, this is the
preserve of philosophy. However, in order to avoid entanglement in debates that could all too easily divert attention away from the principal theme of the thesis, I am starting with the assumption that there is no absolutely secure starting point for knowledge, and that nothing is known with such certainty that all possibility of future revision is removed. Abandonment of the notion that knowledge is built on an unshakeable foundation does not mean, though, that the traditional view of truth has been abandoned.

Medieval philosophers and theologians, whose beliefs and methods had much of their ancestry in the Athenian School of Socrates and Plato, started with the assumption that God and the universe can be, at least partially, understood by the human mind. Accepting the Scriptures as interpreted by the Church, and certain premises in the works of Aristotle and Plato as authority, they upheld the supremacy of reason and deduced by logical methods what the facts ought to be. There was, therefore, no reason at all for them to look through the telescope of Galileo, and they could deny with confidence the theory of Copernicus, and the fact that things heavy and light could fall to the ground at the same rate, even though Stevin, de Groot and Galileo had demonstrated that fact experimentally.

The men of the Renaissance, when they founded modern science, started with the same assumption – namely, that nature is intelligible, and they used the same methods of deductive reasoning with inductive theories being an essential part of the procedure. But the authority was different, for primarily it was empirical, with observation and experiment being both the starting point and the final arbiter. The essence of this new experimental method was an appeal from the completely rational system of the philosophers and theologians, to the tribunal of facts – facts which bore no relation to any philosophic synthesis then possible. The shift of authority was a fundamental change, for it opened up a new route by which knowledge could be
gained (see Table 2).

Table 2  
Comparison of Philosphic and Theological Knowledge with Natural Science

<table>
<thead>
<tr>
<th>Founders</th>
<th>Medieval philosophers and theologians</th>
<th>Natural science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assumption</td>
<td>All things can be (at least partially) understood by minds of humans</td>
<td>Nature is intelligible</td>
</tr>
<tr>
<td>Authority</td>
<td>A philosophic (i.e. a belief) system</td>
<td>Observation and experiment</td>
</tr>
<tr>
<td>Methods</td>
<td>Reason</td>
<td>Deductive reasoning and inductive theories</td>
</tr>
<tr>
<td>Outcomes</td>
<td>What the facts ought to be</td>
<td>Theories</td>
</tr>
</tbody>
</table>

The implications of this shift were more perplexing, for, to the Aristotelians, the real world was disclosed by the senses - a world of colour, sound and warmth, of beauty, goodness and truth. Under the analysis of Galileo, colour, sound and warmth vanished into mere sensations, and the real world appeared to be 'but particles of matter in motion' (Dampier 1961, p xvi), which seemed to have no connections with the good, the beautiful and the true.

So emerged what was, perhaps, the first problem of a theory of knowledge, namely the difficulties which underlie the apprehension of matter by a non-material mind. However, the problem did not deter Newton's disciples (especially the French philosophers of the eighteenth century) from quickly converting his science into a mechanical philosophy, in which the whole of the past and future was theoretically calculable - and man became a machine.

As it was found that more and more scientific knowledge could be expressed in terms of physics, confidence was gained in the method, and there arose a belief that a complete physical or mechanical explanation of all existence is theoretically possible. Modern scientific philosophy shows, however, that by its inherent nature and fundamental definitions, science is but an abstraction and can never represent the
whole of existence. Concerning the sources of our knowledge, the requirement, as outlined by Phillips (1993) is to find and use the best and most reliable sources – those which are least likely to lead us into error. This is of course an idealist approach and all sources are liable to lead us into error at times.

Experience is one of those words that has had accumulated an assortment of meanings over the years. Originally it meant the act of putting something to the test (proof by actual trial), a meaning that later evolved to equate with what amounted to an ‘experiment’. More recently experience has come to be associated with observation of, or practical acquaintance with, facts or events considered as a source of knowledge, such as when we refer to experience in a craft or profession. The empiricist concept of experience was ‘unknown for most of human history’ (Macintyre 1985, p80), being invented in the eighteenth century as a device to close the gap between what seems to be and what actually is, that is to say, between ‘appearance’ and ‘reality’. By contrast, the natural science concepts of observation and experiment were intended to enlarge the distance between ‘seems’ and ‘is’. The lenses of the telescope and microscope were given priority over the lenses of the human eye, and natural science created a sharper distinction between appearance and reality. The meaning of ‘experiment’ and the meaning of ‘experience’ thus diverge more sharply now than they had done in the eighteenth century. For a while at the time of the Enlightenment, these two incompatible ways of approaching the world, namely empiricism and natural science, co-existed in the same culture, but the mechanistic approach to human behaviour would eventually flounder. Experience, though, as the aptitudes, skills, judgements etc resulting from practical acquaintance, or from what has been undergone,
remains a legitimate source of knowledge.

Those issues of some relevance to adults learning science will now be explored in more depth. There are three basic questions that thinkers and researchers have put to themselves over the years as they have struggled to understand how we come to know what we know. Firstly, what is there that can be known? – the ontological question. Secondly, what is the relationship of the knower to the known (or the knowable)? – the epistemological question. And thirdly, what are the ways of finding out knowledge? – the methodological question, which looks at the methods and rules for the conduct of inquiry?

Some understanding of the theory of knowledge is considered an essential perquisite to a study of learning, and so there will now be a brief examination of those theories of knowledge that have been most influential in the Western world over several centuries. Some methods of human knowing will be looked at with the intention of providing the context for this study into adults learning science.

It was Aristotle, student and associate of Plato for twenty years, who, by insisting that first principles be induced from observational evidence, thereby held to – if not defined – empiricist doctrine. The impact of his achievement on intellectual life in the West was, however, delayed until the latter part of the twelfth century because, until then, his writings on science and scientific method were not translated from Arabic and Greek sources into Latin. Thus it was that, for the next three hundred years or so, the main activity of medieval scholars centred on discussions and criticism of Aristotle’s view of scientific procedure, in particular, his position on evaluating competing explanations, and his claim that scientific knowledge is necessary truth, namely, that truth which is incapable of being false. Some scholars, for example, Francis Bacon (1521–1626), emphasised the practical application of scientific
knowledge, though this stood in marked contrast to Aristotle's position that knowledge of nature is an end in itself. Others, for example, Isaac Newton (1642-1727), affirmed Aristotle's theory of scientific procedure and, in applying his Method of Analysis to some deservedly famous experiments, was able to demonstrate the value of experimental confirmation, as well as the feasibility of deducing consequences that go beyond the original inductive evidence.

Bacon is credited with a new scientific methodology put forward to overcome supposed deficiencies of the Aristotelian theory of procedure. The two principal features of Bacon's new method were an emphasis on gradual, progressive inductions, and a method of exclusion, the application of which was designed to help decide the issue between competing explanations.

The modernist empiricist approaches of deduction and induction are both dualist in nature — locating the mind inside, and the world outside, the boundaries of the skin. Descartes' (1596-1650) interpretation of a dream he had in November 1619, led him to believe that he had been called, by the Spirit of Truth, to reconstruct human knowledge in such a way that it should embody the certainty hitherto possessed by mathematics. Descartes' theory of knowledge held that there are two sources of our knowledge: 1. that which the intellect acquires of its own nature, i.e. intuition, and 2. reasoning, through comparison of two or more objects. Thus the nature of an unknown thing is determined by its relation with known things.

Descartes established a method for arriving at truth through rules which enabled the correct choice of things (propositions etc.) to which the mind should turn. This method would train us to distinguish between what is absolute and what is relative. The problem is that deduction from intuitively self-evident principles is of limited use in science as it yields only the most general of laws. Descartes theory of scientific method, including the role of hypotheses and the value of experimental confirmation,
and its general breadth of scope, contributed to its appeal in the seventeenth and eighteenth centuries.

These ideas inspired Kant and, through Kant, Piaget and the radical constructivists, for example, Glassersfeld (1970, 1987), but this rationalism fails to address adequately the issue of how new mental structures develop out of old structures. The problem with rationalism from the point of view of learning theory centres on the issue of how a being devoid of contact with the world through the senses, could ever amass the materials needed to exercise its reason. But empiricism is not without its problems either - the photoreceptive film in my camera receives plenty of data but I do not consider it to know things about the world - so we must compromise and allow that rationalism can say that we do get some of our knowledge from reason. However, Hofstadter (1979, p 365) does argue that, the knowledge that cars are smaller than mountains is an example of a piece of knowledge that can be created by deduction — as compared with a piece of rote memorisation. He claims it is not stored in any single symbol in the brain, but produced as a result of the activation, followed by mutual interaction, of many symbols, for example, those for ‘compare’, ‘size’, ‘car’, ‘mountain’, etc. The implication is that the knowledge is not stored explicitly, as a packet of information, but implicitly in a spread about manner; and so, such simple facts as relation of sizes of objects have to be assembled rather than merely retrieved.

John Locke (1632 – 1704) in the introduction to his Essay Concerning Human Understanding published in 1690, explains that his purpose is to inquire into the origin, certainty, and extent of human knowledge, together with the grounds and degrees of belief, opinion and assent. He wanted to determine, in other words, the ways in which we come to know, the different sorts of things we can know, the types of evidence by which different sorts of statements can be established, and the degrees of certainty appropriate to the different varieties of statement and different
weights of evidence (O'Connor 1952 p26). By raising the nature of knowledge as a problem, Locke was introducing a new point of view into European philosophy, and this point of view has dominated the subject since his time. He was also the first to develop a suggestion implicit in the work of Descartes, that philosophy should begin with epistemology. He thought that a study of human understanding and its functions would enable people to find out the sorts of enquiries for which our minds are naturally filled. If we fail to examine the capacities of our minds in this way, we are in danger, Locke thought (Fraser 1959 Introduction p4) of engaging in speculations which are far beyond those capabilities. Locke insisted that the most that can be achieved in science is a collection of generalisations about the association and succession of "phenomena". These generalisations are probable at best, and do not satisfy the rationalist ideal of necessary truth. However, his theory does argue that experience is the source of all our knowledge and this prepared the way for the development of psychology as an independent science.

The realists — championed by Bacon, and Hume (1711-1776), compel nature to bear witness, inducing new knowledge or understanding in the form of rules or laws from the accumulation of data, by perceiving the regularity of events in the world. The procedure compares with information processing which, although adequate at handling informative transactions with the world, is unsatisfactory for transformative interactions. This inference by induction is more risky than deduction — you can never be sure, and the knowledge could be invalidated by subsequent experience. Realists look to correspondence with reality by way of verification, but induction (along with Piagetian synthetic deductivism) has been characterised as a head fitting approach to learning and cognition (Brown 1975).

Induction, the inference from particular to general, is a line of reasoning often held to be the basis of science; although Hume, in his *Enquiry Concerning Human
Understanding (1748) pointed out that, because an event has occurred in the past is no logical reason to suppose it will be repeated in the future. The objection is often rejected, but with the acceptance that, if there is a truth to be known, inductive procedures are the best way of getting to it. But, in addition to its ability to explain, it is also a feature of science to predict, and in this second stage of scientific inquiry the generalisations reached by induction, are used as premises for the deduction of statements about the initial observations. This inductive – deductive nature of science may be represented by means of a concept map:
David Hume, an empiricist, maintained that all our knowledge is derived from experience (sense impressions). He thus echoed Aristotle's dictum that there is nothing in the intellect which was not first in the senses, and his claim that it is impossible for us to think of anything which we have not antecedently felt by our senses, has been reinterpreted as reinforcing Baconian inductivism. The implication of Hume's approach is that science begins with sense impressions, and can
encompass only those concepts which are 'constructed' somehow out of sense data, a view that is consistent with Aristotle's Method of Analysis, but not with Newton's Axiomatic Method, which depends on what can and cannot be deduced.

Immanuel Kant (1724–1804) conceded that, if the form and content of scientific laws wholly derive from sense experience, there is no escape from Hume's conclusion. But Kant was unwilling to grant Hume's premise, and argued that although all empirical knowledge arises from sense impressions, it is not the case that all knowledge is given in these impressions. Kant distinguished between the matter and the form of cognitive experience, holding that sense impressions provide the raw material of empirical knowledge, but that the knowing subject itself is responsible for the structural – relational organisation of this raw material. The relevance of this to my study on adults learning is that Kant believed that Hume had oversimplified the knowing process by reducing the operations of the mind to a mere "compounding, transposing, augmenting and diminishing" (Losee 1972, p 107) of ideas. According to Kant, Hume's inadequate theory of knowledge was associated with an equally inadequate theory of science. Kant believed that Hume was preoccupied with inductive generalisations, and held that this emphasis draws attention from the most important feature of science – the attempt to achieve a systematic organisation of knowledge. Kant's own theory of knowledge was more complex, specifying stages in the organisation of cognitive experience.

One of the problems of science has been the difficulty of how to get from observations to laws and theories. John Herschel (1792–1871) maintained that there are two distinct ways: i) the application of specific inductive schema and ii) the formulation of hypotheses. Herschel's view of the context of discovery may be represented schematically, as follows:
Herschel managed to combine the Baconian ideal of a hierarchy of scientific generalisations with an emphasis on the role of the creative imagination in the construction of the hierarchy, an aspect developed more thoroughly by Warnock (1994) – though not with any particular reference to science. He also demanded that the scientist assume the role of antagonist against his own theories (thereby anticipating Popper’s views), and seek both direct refutations and exceptions which limit the range of applications of these theories.

Karl Popper (1902–1994) was interested in the growth of knowledge generally, but particularly in the growth of scientific knowledge, as opposed to the mere accumulation of observations; and he identified this growth with the repeated overthrow of existing scientific theories and their replacement by more satisfactory ones (Popper 1963, Ch 10). The method of learning by trial and error – of learning from our mistakes, is “fundamentally the same whether practised by higher or lower
animals and applies equally to scientific knowledge as to knowledge in general" (Popper 1963, p 216). But Popper claims that a study of scientific knowledge is a fruitful way of studying the growth of knowledge in general. Popper's thesis concerning the growth of knowledge is also relevant to this study, and has several dimensions: firstly, that a criterion of relative potential satisfactoriness can be applied to new theories. This characterises as preferable the theory which tells us more, that is the one having a greater amount of empirical information, is logically stronger and has greater explanatory and predictive power. It can, therefore, be more severely tested, and, in short, has a higher degree of empirical content or testability. In this context, it is interesting that Lavoisier's classical experiments which show that the volume of air decreases while a candle burns in a closed space, do not establish the oxygen theory of combustion, but rather they refute the phlogiston theory that had dominated (and held back) scientific thinking for a century. Secondly, high information content, by definition, means low probability - and thus a high probability of being falsified. Consequently, one of the aims of science is to achieve a high degree of refutability.

Thirdly, science starts with problems and not from observations, although observations may give rise to a problem if they clash with our expectations or theories. The conscious task before a scientist is always the solution of a problem through construction of a theory which solves the problem. But every new theory raises new problems and it is largely through the new problems which it raises that it is fruitful. Fourthly, the task of science is the search for truth, which is seen as correspondence with reality, and the approaches tend to be either, via the route which holds that whatever cannot be supported by positive reasons is unworthy of being taken into serious consideration, or by a route which says that whatever can in principle be overthrown by criticism, yet resists all our efforts to do so, may quite possibly be false, but is not unworthy of being seriously considered.
Popper insists that deductive, and other methodological systems by which theories are developed, be regarded as stepping stones rather than ends – as important stages on the way to richer and better testable scientific knowledge. He develops the argument (Popper 1963, p 221) with the thought that, "it is in the rational choice of the new theory that the rationality of science lies, rather than in the deductive development of the theory". Thus the scientist will be interested in the methodology only in so far as it contains those choices, those rejections, and those decisions which show we have learnt from our mistakes and, thereby, added to our scientific knowledge. My interest is in the methods as means by which new knowledge replaces old knowledge in a person, whilst Popper is more concerned with the growth of scientific knowledge as an abstract concept.

One of the things expected of science is the ability to understand and explain phenomena, and learners expect to acquire some of this ability from their studies. By 'understanding' a phenomenon, a scientist usually implies that she or he can fit the occurrence into a pattern of events which can be summarised in a well defined physical law. Descartes held that a hypothesis is justified by its ability, in conjunction with fundamental laws, to explain phenomena. Frequently he suggested hypotheses that were based on analogies - parallels, drawn from everyday experiences but, while the use of pictorial analogies may have contributed to the popularity of his theory of the universe, reliance on them also led him astray. For example, in his explanation of the circulation of blood in the human body, Descartes committed himself to an inappropriate analogy. His account (Kenny, 1970, vol.15, p 236-237) conflicted with the facts which he knew, having read Harvey's book on circulation, yet he elected to defend his own hypothesis. Despite what might be expected to be a set-back for the use of analogies, the physicist N.R. Campbell held that it is not sufficient for a theory merely to display the required formal structure, it must, in addition, be associated with an analogy (Campbell 1952).
Carl Hempel (1905-1997), a German born philosopher, while conceding that analogies are often of value in guiding further research, and that they have been influential in the historical development of the sciences, maintained that since analogies do not occur as premises in the deduction of experimental laws, they are not part of the structure of scientific theories. A model, however, does have the same formal structure as a theory for which it is a model, but the epistemological structure is simpler. There are, however, potential dangers of thinking of a theory by way of thinking of a model, because one can assume that concepts involved in the theory correspond to all properties of the objects in the model, for example, that the electrons in an atom have all the spatial properties of the balls in a 'solar system' model of an atom. If models are used in the teaching of science, as frequently they are, then both teachers and learners must never forget that they are engaging in an 'as if' way of thinking (Braithwaite in Grandy 1973, p 52): the theoretical concepts in a scientific theory behave as if they were elements in the model, but only in certain respects.

Harré (1970) argued for a shifting of emphasis from the formal deductive structure of theories to the associated models. He distinguished three component parts to a scientific theory: i) statements about a model, ii) empirical laws, and iii) transformation rules, but insisted that the existential hypotheses suggested by the model, should receive more emphasis than the deductive structure which may be developed by, or from, the descriptive hypotheses. A good example is provided by Mendeleef's (1834-1907) predictions of the existence of hitherto undiscovered elements, where predictions of properties were subsequently shown to be satisfied by the elements scandium, gallium and germanium. According to Harre (1970, p 125), if no existential hypotheses are suggested by a theory then, that theory does not advance our understanding of the underlying mechanisms of natural processes. Prediction has become more important than the construction of theories as general
statements; and Huygens’ account of the methodology of science, written in the Preface to his Treatise on Light (Huygens 1690, 1962, p vi, vii), that it is “possible to establish a probability which is little short of certainty when one employs the hypotheses to predict new phenomena and finds expectations realised”, has proved to be a prescient statement.

Dissatisfaction with both the ontological assumptions (the form that knowledge takes, as well as its location in the mind, or in society), and epistemological issues (concerning the validation of knowledge about the external world), has provided some of the motivation for the search for an alternative approach. Gergen (1994, p 22) writes: “So severe are the problems of dualist epistemology, materialists, phenomenologists and Wittgensteinians alike have since opted (albeit on differing grounds) for an abandonment of dualist metaphysics”. The notion that the mind is not in the head, whilst counter intuitive, has become a key tenet of his social constructionist theory, and shares much in common with the view espoused by Rorty (1982, p 161), who suggested that we give up what he calls “the neurotic Cartesian quest for certainty”. The issue in the eyes of post modern psychologists and philosophers is no longer one of accounting for the development of new mental structures; rather it is one of accounting for changes in language - the sudden development of new ways of talking about the world. The linguistic community is relied on to sort out knowledge claims, and truth is a property of language; “nothing more than what our peers will let us get away with saying” (Rorty, 1979, p 176).

Prigiogine & Stengers (1984) pronounced the end of certainty and described a world that is responsive, non-linear, rational, and self-modifying, in stark contrast to the earlier mechanistic Newtonian world which was isolated, solitary, linear, orderly and stable. Chaos theory – which they were describing – proposes that living systems operate according to their own principles of organisation. The theory challenges
some of the most powerful educational theories which underlie current practices. It proposes that learning occurs not only in the 'zone of comfort', but especially during times of confusion, and that the goal of teaching is not to transmit knowledge but to transform it. Consistent with Doll's (1993) ideas opposing the Tylerian step by step approach to educational objectives, Domaingue (1988) proposed the analogy of a computer programme, in which learners journey through various 'hypercards' that correspond to their learning interests. A consequence of this line of thought was that learners come with unique histories and learning experiences – hardly a revolutionary concept to anyone who has spent time in adult education. A more interesting (to my mind) tenet of chaos theory is that, knowing is transactional and never complete, and there will always be something that is not yet apparent (Osberg & Biesta 2003). In this respect, knowledge is not sought for the purpose of understanding the world as it is, but rather for the purpose of finding novel and creative ways of interacting with the world, and discovering ways of creating greater novelty and complexity.

So much for the postmodernist epistemological strategy; the ontological strategy is also very simple - that knowledge resides in language, as opposed to mental structures, in "temporary locations in dialogic space", to use Gergen's (1995, p 30) colourful expression. But, as Orton (1995) surmises, the question as to how it is that we come to know anything new arises irrespective of one's ontological commitments. Thus, knowledge may reside in language, but that does not solve the problem of how new forms of this knowledge come into being. Rorty, by way of explanation, offers the notion of random linguistic mutation (cosmic rays scrambling crucial neurons), but seems to have a somewhat cavalier attitude: "It hardly matters how the trick was done" (Rorty 1989, p 17). It is as though he downplays the problem of idea generation because he cannot account for it in his philosophical system. However, it is significant that Holton's (1988) assessment, that studies of men of genius do not
help us to understand how personality relates to scientific achievement, has yet to receive a serious challenge.

A further approach to the problem, and one which receives some support from Miller's (1987) careful study (painstakingly pieced together from scientists' notes) of the discovery process in physics, offers many illustrations of the role played in idea generation by some kind of 'pre-scientific' metaphoric thinking. This approach, as Prawat (1999, p 60) advises, was first formulated by the American philosopher C.S. Peirce (1839-1914), and for which he appropriated the term 'abduction', consists in the studying of facts and the working out of a theory to explain them. The concept was elaborated by John Dewey (1859-1952) (Prawat 1999, p 60-62), who had been a teacher of science, and so, together they argued that ideas enjoy certain advantages as carriers of meaning that other constructs lack, for example, they can overcome the problem which afflicts other constructs - of skin boundedness, a term first introduced by Bentley (Prawat 1999 p 51), a colleague of Dewey's.

Prawat (1999) gives a full account of Peirce's view of the process of idea development, as being one of metaphoric projection in which metaphors, like 'food factory' for leaves, or 'pump' for heart, are taken as examples. Ideas are said to originate outside of language, yet in the stage of their development in which they are located in a system of related ideas (the metaphors), abduction has to rely heavily on social discourse. Miller's (1987) study of the development of what had been Albert Einstein's new idea - the relativity of time, shows that, although his thought experiment was language triggered, the basis for that experiment lies outside of language. Einstein himself was insistent about the fact that, for him, thoughts did not seem to come in any sequence of words: "I very rarely think in words at all" (Miller 1987 p204). Wolfson captures this sentiment when he writes that, words "are nothing but floating buoys which signal the presence of submerged unuttered thoughts" (Wolfson 1947, p 106-107).
The question arises as to whether ideas are generated through a metaphoric process that lies outside language, or is metaphor the mediator between non-linguistic ways of knowing and language? There is certainly reasoning from the known to the new using of ideas as the instruments of knowledge. Prawat (1999, p 47-76) elaborates Peirce’s useful comparison of the modernist theories with abduction, by suggesting that deduction proves something must be, induction shows that something is actually operative, whereas abduction suggests that something may be.

Mention needs to be made of the philosophical doctrine of pragmatism – that which works out most effectively in practice - invented by Peirce, a chemistry graduate who linked it specifically to science and saw in it a road to objective standards. Pragmatists taught that we must make do with plausible information adequate to the needs of practice, as there is no possibility of achieving authentic knowledge. Dewey developed a systematic pragmatism addressing the central questions of epistemology and based on intelligent inquiry experimentally testing hypotheses created from previous experience. Dewey attacked the notion that education consists in the transmission of a body of knowledge, placing stress instead on critical thinking, individual experimentation (discovery learning) and problem solving. Experiences somehow become ‘intellectualised’ when they are illuminated by ideas, whether these are definite or general. Deweyism has been criticised on grounds that what may be induced from group learning (the project method is an application of his principles), may be conformism to accepted mores (Bantock, 1965 p136). However, in the decades of the second half of the twentieth century, two theoretical changes took place: from the behavioural to the cognitive viewpoint and from broader to more narrow theory ranges. The shift to a cognitive approach was connected to the appearance of Gestalt psychology (Hewstone et al 1988 p 15) in America in the 1960’s. Ausubel’s assimilation theory of learning formalised within cognitivist terms
the pragmatic trial and error nature of learning which Dewey encapsulated.

The absence of consensus, whilst being a stimulus to philosophical debate, can have the opposite effect on the fields of education and natural science (at a more elementary level). Thus, we find Carr (1995) fiercely attacking empiricism because it never managed to provide an epistemology that met the needs of the natural sciences, while Kuhn (1962), and Popper (1963) were busily undermining the very principles of empiricism. Popper’s contention that no scientific knowledge can be regarded as established, so long as the scientist knows only the evidence that confirms it, and has not undertaken to discover evidence that disproves it, was taken on board by the scientific community, and these somewhat revolutionary ideas were developed by Lakatos (in Lakatos & Musgrave, 1970), a sophisticated falsificationist, who argued that a theory is acceptable only if it has corroborated excess content over its predecessor (rival).

Thomas Kuhn (1922-1996) demonstrated that sociological factors have been important in the development of scientific knowledge. He also saw claims for scientific advances as largely circular arguments because they do not conform to the format in which observation always precedes theory, with logic and solid data always pointing to one, and only one, theory. Although his objectives were shared by sociologists of the ‘Edinburgh School’, their methodologies are different and Kuhn would not have shared their belief that scientific knowledge is only a communal belief system with a dubious grip on reality.

Lawson uses the language of Kuhn (1962) when discussing how adults learn: “we operate with paradigm examples and change the paradigms when they fail in too many instances” (Lawson 1998 p135). However, beyond making the point that paradigms and paradigm shifts apply adequately in some circumstances but not in others, Lawson does not present a critical appraisal of Kuhn’s theory. An example of where the theory seems deficient is Newtonian physics which has not been
abandoned despite inadequacies in its explanatory power regarding some phenomena. Although Kuhn may be imprecise about the nature of paradigms and paradigm shifts, his theory remains a useful vehicle for progress in describing the way a theory is revised when it fails to work. This thesis is more concerned with the process of learning – that which involves an interpretation and translation into our concepts and fund of knowledge acquired previously.

There was need for a fresh approach, and it came in the name of constructivism. Advocates of constructivist models have in common that, they believe that theories and expectations precede and guide the observations an individual makes, and are not the result of observation. Constructivist pedagogy has existed, albeit unlabelled as such, since the fourth century B.C. Constructivist epistemology, as an offering to teachers of a "moral imperative for deconstructing traditional objectivist conceptions of the nature of science, mathematics and knowledge and for reconstructing their personal epistemologies, teaching practices and educative relationships with students" (Hardy & Taylor 1997, p 148), can be said to have emerged following the publication of a paper by Driver & Easley (1978). This claimed that achievement in school science depends more on the student's specific abilities and prior experience, than on general levels of cognitive functioning. Teaching would no longer be seen as filling empty minds. Constructivism, therefore, emerged as a theory of learning, though it is necessary to remember that learning theory is not epistemology, and the mechanisms whereby sense and nonsense are learnt are the same. However, constructivism is more open to, and hence more cautious about, the fact that what is learnt may be ideology or a way of being socialised – hence it is more inherently sceptical. The distinction between belief and knowledge (recognised since at least Plato's time) has been obscured in the development of constructivist theory, though this theory has dominated science education over the past thirty years. Matthews (2000) has highlighted its limitations in relation to teaching the content of science.
Many educationists have written about constructivist principles but Grayson-Wheatley, a Canadian science educator, has summarised them succinctly: "The theory of constructivism rests on two main principles... Principle one states that knowledge is not passively received, but is actively built up by the cognising subject... Principle two states that the function of cognition is adaptive and serves the organisation of the experiential world, not the discovery of ontological reality... Thus we do not find truth but construct viable explanations of our experiences" (Wheatley (1991, p 10). Schwandt (1998) corroborates this idea with his conclusion that human beings construct or make knowledge, rather than discovering it. He thought that the mechanism by which this occurred involved the invention of concepts, models and schemes to make sense of experience; these constructions would then be tested and modified as experience proved necessary. Thus, it seems that, it is the 'active' role of the learner, which entails more than 'finding out' something that was out there waiting to be discovered, that differentiates itself from discovery learning and from didacticism as well.

In an article explaining the implications of constructivism for practising science teachers, Lorsbach and Tobin argued that the constructivist epistemology asserts that the only tools available to a knower are the senses. It is only through seeing, smelling and tasting that an individual interacts with the environment. With these messages from the senses, the individual builds a picture of the world. Therefore, constructivism asserts that knowledge resides in individuals (Lorsbach & Tobin1992). Matthews (2000) disputes the claim that people build up meanings from sensory inputs; rather, he takes the view that meanings are learned with varying degrees of accuracy.

Harlen (1999) makes the interesting observation that, children already have formed ideas which they bring into new science investigations, influencing both what they do
and what sense they make out of what they find. Their learning, therefore, is not a
discovery of some new ideas, rather the development of the ideas they bring and are
constructing for themselves.
The theoretical problem for constructivism is that, if knowledge cannot be imparted
and must be a matter of personal construction, then how can those without
knowledge come to know of complex conceptual schemes such as valency and
oxidation, that have taken many years to develop? Even Driver, one the most
influential constructivists in science education conceded that, "the theory that rusting
is a chemical reaction between iron, oxygen and water, resulting in the formulation of
a new substance, is not one that students are likely to generate for themselves"
(Driver et al1994, p 206).

Whilst at school I was taught in both science and other subjects by the
transmissive method, with much of the body of knowledge learned by rote,
this was well suited to the examination style and so the process appeared to
be unproblematic. When learning to teach science I was introduced to
discovery learning and constructivist principles, both of which were plausible
and attractive. In retrospect, I fear I wasted many contact hours with pupils in
efforts to enable the content of science syllabuses to be known by them
according to these ideals. I admit to never finding ways in which abstract
notions, for example, valency, could be generated according to constructivist
principles and, in the end, I wondered just how much more a phrase such as
‘construction of knowledge’ says than the old word ‘learning’, or the phrase
‘personal construction of meaning’ than the word ‘understanding’. The
classroom teacher is conscious of the responsibility for ensuring that his/her
students have knowledge of scientific orthodoxy, and that they are trained
adequately in the methods and procedures of the discipline. I found I could placate my frustrations to some degree under the guise of ‘training’, for in this area I, and not the students, could be the arbiter of truth. These, not entirely satisfactory, experiences testify to the unsolved problem of how complex conceptual knowledge can arise from simpler knowledge.

There is no reason why constructivism should be applied only in the cognitive domain, though most of the models for thinking about the learning of science have approached the problem in purely or predominantly intellectual terms. The assumption in this approach is that, difficulties in learning science reflect structural or functional characteristics or, more frequently, limitations of the cognitive system. Remedial action is therefore aimed at freeing the ‘cogs’ of cognition. But maybe the problems of school science learning should be located within the wider context of pupils’ emotional, personal and social lives, as has been hinted at by Bloomer (2000). Claxton (1998) proposes that, a pupil’s achievement and demeanour in lessons can only be properly understood as the response of a whole person to a complex whole person predicament.

Thus, the nature of the intellectual task is represented by one cluster of variables in the personal equation that determines how to be in a lesson. Other variables are to do with personal concerns and feelings, unresolved issues from outside the classroom, competing priorities and ambitions, assessment of personal capabilities and limitations, social mood of the class as a whole, feelings and assumptions about the teacher etc. The implication is that pupils are architects of their own learning and authors of classroom behaviour, not caged birds imprisoned within the limitations of their cognitive systems. Thus the stance they adopt in a lesson is the outcome of a subtle decision-making process, which in its turn influences strongly what and how they learn.
It appears that, not only is there an absence of consensus regarding the nature of methods of knowing, there are also conflicting views on the nature of the world known by science, which seems to reflect a lack of knowledge regarding both the content and method of science.

Lonergan (1957) made an heroic effort to understand the process of human knowing. According to Lonergan, human knowing is a dynamic structure, involving several distinct, irreducible but interrelated activities. The activities include: seeing, hearing, touching, tasting, smelling, inquiring, imagining, understanding, conceiving, reflecting, marshalling and weighing the evidence, and judging. Lonergan refers to human knowing as a three-levelled process involving experience, understanding and judgement, and each of the above activities can be located on one of the levels, for example, activities involving the senses are located on the level of experiences. Although it is possible for any of the above activities to be complete themselves, Lonergan claims they do not, and cannot, individually, fully constitute human knowing. Without prior presentations by the senses or by the imagination, there is nothing to inquire about and nothing to be understood, and so there can be no understanding without the prior occurrence of experience. Understanding and experience together do not fully constitute human knowing, because judgement without understanding is arrogance, and the evidence in support of a prospective judgement is found in experience. His view of human knowing, then, was that it is not any of the qualities of experience, understanding or judgement, nor is it a combination or mix of any of them; it has to be seen as an occurrence in which each quality makes an essential contribution. This whole is not a static structure, however, but is self-assembling and self-constituting. It is experience that stimulates inquiry, brings intelligence to act and leads from experience and imagination through insight to the emergence of concepts. Concepts stimulate reflective inquiry which leads to judgement, where what is understood is either affirmed or denied, or left open to
doubt, thus leading to further inquiry, and a repetition of the same set of operations.

Some important features of insight can be identified. Insight comes as a release to the tension of inquiry, it comes suddenly and unexpectedly, there are no rules to ensure its occurrence. Insight is in no way like a logical deduction of conclusions from premises, although it can be formulated in such a manner. Polanyi (1958) argued that established rules of inference offer public paths for drawing intelligent conclusions from existing knowledge. The pioneer mind, which reaches its own distinctive conclusions by a leap across a logical gap, deviates from the commonly accepted process of reasoning to achieve surprising results.

It is the recognition of insight as a non logical operation that is an integral part of human knowing, that is a central theme to Polanyi's argument. Insight involves a grasp of relations in what is presented by the senses or the imagination, and so goes beyond the given, but the movement from data to theories is not simply a logical process. Insight is a function of inner circumstances and not outer conditions. To have an insight, one must be faced with a question that specifies the nature of the investigation, and one must also possess the relevant data. Insight is radically different from sensation: there is no analogy between looking and understanding, and the non-scientist can gaze at the same data as the scientist, but does not have the same insights.

New and interesting studies are being conducted, with new models of learning and teaching being considered by Bereiter & Scardamalia (1996), amongst others. But it is to neuroscience that we are likely to be turning increasingly for new knowledge. For example, Leslie Hart (1983) has highlighted one of the key characteristics of the neocortex: the ability to detect and make patterns of meaning. The process involves deciphering clues, recognising relationships and indexing information. The clues that the brain assembles are best recognised in a Gestalt format, not in a digital, 'adding
up' process. Hart claims that pattern recognition depends heavily on what experience one brings to a situation, so constructivist principles seem to apply here. And, while Gregore (in Tobias 1994) has concentrated on the differing kinds of abilities shown by different personality types (the abstract sequential types are said to have the best ability to conceptualise an idea), Allan Snyder and John Mitchell, of the Centre for the Mind at the Australian National University in Canberra, in a new interpretation of the powers of savants, have argued that such people have access to a world of unconscious information denied to the rest of us. Rather than savants having special powers - as others have argued - they claim (Snyder & Mitchell 1999) that the same powers exist in everybody's brains, but only those with a rare abnormality can access them.

That unconscious operation of the brain can explain why 'sleeping on a problem' often leads to a solution; Professor Snyder, writing in The Times (22.03.1999 p.18) newspaper suggests that, periods of creativity may follow times when the brain may be thinking about a problem without our being conscious of it doing so. If the mechanism for this incubation could be understood, then maybe creativity could be increased. Savants have long been a puzzle to philosophers and scientists for the remarkable feats they can perform, for example, the multiplication of large numbers in their heads. Snyder & Mitchell (1999) say that in a normal brain the underlying arithmetical operations are overlaid by conceptual processing that obscures them. Savants are often autistic which means they lack the ability to conceptualise, so unconscious information comes through to them un-sifted. They suggest that drugs might allow non autistic people to tap into their unconscious mind and match the feats of savants, but of more interest to educators is the possibility of increasing creativity by encouraging the unconscious processes of the brain. Meanwhile, a team led by Marcus Raichle (1998) of Washington University at St Louis, by using a scanner to map neurological activity, has demonstrated that paying focal, effortful
attention to something, calls large regions of the brain into action. But once the brain finds an optimal way to respond to a certain situation, the wider scaffolding rapidly falls away. It is not that practice makes more efficient use of the pathways that were active during conscious learning, it is that the brain no longer needs to carry a running memory of its recent performance, and so the response can be reduced to its bare essentials - creating a memory trace in motor or language areas, which then lies dormant until the right input passes by again. Raichle believes the scanning data suggests that the brain has two distinct sets of pathways, one for dealing with novelty, the other pathway for habits. The suggestion is that over a lifetime of conscious learning the brain accumulates thick strata of local routines - habits of perception and reaction that allow most things to be processed swiftly and automatically. So what forms our centre of attention is essentially self-selecting - the bit of the moment that turns out to be the least routine. Our layers of habit form a mental filter that let only the novel or difficult grab our attention. Raichle is now turning his attention to discovering those areas of the brain which you have to inhibit to be able to think about things in a novel way.

As to the question of whether a single theory can encompass the entire learning process, Tolman (1959, p 93) commented, "I think the days of such grandiose, all-covering systems ... are, at least for the present, pretty much passé". Possibly the single most important factor in the transition from global learning theories to contemporary learning theories that focus on specific aspects of the learning process, was the realisation that our biological systems constrain what we do or do not learn about. Traditional learning theory was "premised on the assumption of the generality of the laws of learning across all stimuli, responses and situations" (Mowrer & Klein 2001, p 17). There seem to be many research findings at odds with these assumptions, but what is clear is that our biological underpinnings influence the process of learning and call into question the concept of general laws of learning.
3. SUMMARY

While it was not the purpose of this chapter to attempt a full review of the long history of philosophical ideas about the nature of knowledge and knowing, the identification of some of the ideas that are prominent in epistemology will serve to provide a context for this study. It also demonstrates that human knowledge consists of a series of constructions which, because they are humanly generated, are problematic, namely, indeterminate, unsettled, and ambiguous. This fact can be lost sight of in the arena of science which is widely regarded as the way to discover truth. The next chapter will examine the links between conceptual change and learning.
CHAPTER 3

THE LEARNING PROCESS

1. INTRODUCTION

This chapter begins with a brief look at some contemporary ideas concerning the learning process and then explores aspects of altering concepts that relate to adults learning science. Consideration is then given to some factors which act as barriers to conceptual change, especially problems with reading science texts for learning and comprehension. Though much of the work on reading and comprehension has been pioneered with children, wherever possible, emphasis in this study has been placed on adults learning science.

2. SOME ISSUES RELATING TO LEARNING AS CONCEPTUAL CHANGE

Whilst questions of scepticism and certainty, as they apply to arguments about whether saying one knows a fact allows the claim to a right to be sure of it, are properly the subject matter of philosophy, any investigation into the acquisition of new knowledge must also give some consideration to the nature of that knowledge, and to the consequences of holding particular views. Human beings tend to organise their experiences into coherent, explanatory frameworks, and these are normally expressed in more or less specific sets of words that are commonly referred to as conceptions (Vosniadou 2002). The conceptualisation of knowledge in terms of conceptions, has dominated science education research since the late 1970’s. There is also evidence for the existence of conceptions that differ from the standard conceptions of science, which has led to the invention of terms such as
misconception, alternative conception, etc. (Pfundt & Duit 2004). The robustness of a student's conceptions in the face of efforts to change them, is also well reported (Pine & Messner 2000). Different models have been proposed for describing the conceptual changes that students undergo (Chi 1991), and some studies have identified conditions that support the evolution of initial conceptions held by learners, to scientifically correct ones (Strike & Posner 1992). Although these studies differ in the way they go about inducing change, they share two assumptions: (i) conceptions are located somewhere in the mind, in the form of mental models (Vosniadou 2002), p-prims (di Sessa 1993), or internal structure (Reiss & Tunnicliffe 2001), and that (ii) language is a means for expressing internal conceptions to the outside world, but has little effect on the constitution of the conception.

New and different ways of thinking about knowledge have been proposed by Edwards (1993) and Gee (2004) in which knowledge is thought of in terms of discursive practices. Here the emphasis is shifted from something which is located in the mind, to the word 'conception' - referring to "publicly displayed forms of meaning-making talk" (Givry & Roth 2006, p 1087). Conceptions, therefore, have to be understood and theorised in terms of situations and language in use; they embody a cultural way of articulating the world. While all this seems a very long way from conventional models of interpretation used in science, the demise of positivism has opened the way for alternative approaches such as this.

Traditionally, the word 'learn' referred to the acquisition of knowledge or skill as a result of study, experience or instruction. The steady increase in attention given to learning through experience over the last twenty years, has resulted in some researchers using the term 'learning' as though it described only the acquisition of knowledge or ability through experience. Such a view contradicts the belief that not all modifications of behaviour as a result of experience result in learning; compare
this with the biological phenomenon of 'imprinting' where an experience can determine future behaviour, which is not generally considered to be the same thing as learning. However, experiential learning has come to dominate the scene and many forms of it have emerged, for example, action learning (Revans 1980), transformative learning (Mezirow 1991), and it seems that all forms can be behavioural, action based, cognitive or social. Kolb produced a diagram to illustrate the pathways involved in experiential learning (Kolb & Fry 1975):

Fig. 3 Experiential Learning Cycle, after Kolb

![Experiential Learning Cycle](image)

Though Kolb's representation has achieved some renown and has been published frequently, it has been criticised as overly simplistic and lacking in recognition of the social context of human learning. But these omissions have been the stimulus to other researchers to develop and improve the diagram, so that more details of the learning process can be included. Jarvis, for example, has produced a model to "capture the multiplicity of the different processes of learning" (Jarvis in Olssen 2004, p 32) - this is reproduced on the next page. Jarvis not only identifies different routes (from boxes 2 and 3 in his model), but he also recognises that not all learning is intended, so his categories are sub-divided further, according to intention, or lack of
it. Jarvis uses awareness as the criterion for intention; I think it would be difficult to collect evidence showing that different processes take place depending on the presence or absence of conscious awareness. My interest is in how adults respond to new information and I have made it an assumption that the mechanism of the response is the same, whether the new information is sense or nonsense.

Fig. 4 A Model of the Process of Learning - after Jarvis (in Olssen 2004 p 32)

Novak simply categorises learning to be rote (when the learner memorises new information without relating it to prior knowledge), or meaningful - for which there are three requirements: (i) the presence of relevant prior knowledge, (ii) some meaningful material to learn, (iii) the learner choosing to learn meaningfully. This last point, if correct, would seem to carry an implication that unintended learning could never be meaningful, and I am not sure that either Novak or Jarvis would find that conclusion
acceptable. Both researchers accept the importance of motivation; Novak's first principle in his theory of education (Novak 1998, p 224) states: "there must be motivation to learn. No learning will take place unless the learner chooses to learn". Jarvis (1999, p 38) says: "But if there is a disjuncture between my biography (the sum of my experiences both conscious and unconscious) and a particular experience, I might seek to learn to close it".

Confrey (1990, p 108) argues that, "we construct our understanding through our experiences, and the character of our experience is influenced profoundly by our cognitive lens". Yet it is only fairly recently that recognition of students' prior experiences, and of how they came to make sense of these experiences, have come to be recognised as important elements in establishing effective learning environments. Bendixen, Dunkle & Shraw (1994) draw attention to the way in which the epistemological beliefs about learning and the acquisition of knowledge influence the quality of student learning. They report that it appears that epistemological beliefs may drive the type of information processing a learner uses. Marton & Saljo's (1984) study, referred to later in this chapter, also revealed views of learning as held by learners. My study aims to discover how adults respond to new information regardless of their epistemological beliefs, motivation or intention. It also tests for the existence of any link between the conception of learning by a learner as determined by questionnaire, and the type of learning as revealed in concept maps drawn by the same learners.

Changing and, or, increasing knowledge involves altering concepts, or acquiring new ones, and some implications of this will now be considered. Many terms relating to conceptual change, and many meanings ascribed to these terms, are found in the literature. Thus, in addition to the frequently used term 'conceptual change', are the following terms; 'knowledge restructuring' (Carey 1985), 'belief change' (White & Gunstone 1989), 'conceptual capture' (Hewson 1981), 'assimilation' (Posner et al
1982), 'conceptual exchange' (Hewson 1981), and 'conceptual refinement or extension' (Tytler & White 1996). Some commonality can be identified, and these terms all seem to embrace the replacement, and/or addition, of new ideas that can account for phenomena that could not be accounted for by previous understanding. All of them also hold to the view that knowledge is personally and socially constructed, and that alteration of ideas is a mostly linear process. The possible influence of teacher expectations on the self-conceptions of students, and any effect this might have on their learning, is explored in Flude's (1974) account of theories of social difference in education.

For the purpose of this study, use of the term 'conceptual change' will be confined to my own working definition - 'conceptual change be taken to describe an alteration in existing knowledge, to account for new and, or, more complex phenomena which were not satisfactorily accounted for to the individual, by previous knowledge'. The definition applies to individual knowledge, as opposed to the more general knowledge that may constitute scientific orthodoxy. Conceptual change may move towards this, but it is not required to by definition. The term 'understanding' is often used to indicate the final outcome of a learning process, but I prefer to place learning at the apex of conceptual change, because it describes something that encompasses both memory and understanding; it means to have knowledge of, whereas understanding refers to perception of meaning. There are countless errors, misconceptions, mythologies, ideologies and fantasies that can be understood in themselves (Matthews 2000), but this understanding does not equate with knowledge. If learners and teachers limit themselves to understanding alone, then the possibility of any theory of learning leading to knowledge is severely compromised.

Conception goes beyond what can be presented by sense or imagination. For
example, in the discussion of chemical structure, the concepts of bond length and bond angle emerge. It is possible to consider a 'ball and stick' molecular model, but the reality is in no way like the model. The model helps one to understand, but the understood molecule is not identical with the model; thus, "the movement to concepts involves a movement into the field of the unimaginable" (Danaher 1988, p 52).

Concepts are constituted by the activities of supposing, thinking, formulating, understanding, and defining, and these occur after insight has occurred. As an example of concept formation in chemistry, geometric isomerism will be considered, using the molecule 1,2 dichloroethene.

Fig. 5 Structure diagrams illustrating geometric isomers of 1,2 dichloroethene

Insight into either structural formula enables one to come to an understanding of the particular features of that compound, for example, the number of bonds, the bond angles, and the spatial arrangement of the atoms. The notion of geometric isomers, however, does not emerge from a consideration of the topology of any single structure. To discuss geometric isomerism, both cases must be considered and, through insight into the particular cases, plus further thinking, one is able to grasp that there is a topological difference between the two molecules, and this is related to the relative positions of the chlorine and hydrogen atoms. Thus, the concept of geometric isomerism emerges. To arrive at this concept, and to be able to give a general explanation of the structure of geometric isomers and the grounds for their occurrence, it is necessary to consider more than one case. Conception selects what is essential, namely, the topological difference, which is reflected in the different relative positions of the hydrogen and chlorine atoms, and disregards the incidentals - the size, the colour and the type of diagram, or even the particular chemical
symbols. The function of concepts does not fully constitute human knowing. It is only in the act of judgement which follows insight into data, the foundation of concepts, and the formulation of hypotheses or probabilities, that the process of knowing is complete.

The six conceptions of learning identified by Marton et al (1989) provide a useful framework against which to view data from this study. Three of the conceptions, namely: increasing one's knowledge, memorizing and reproducing, and applying, view knowledge as being 'out there', waiting to be picked up, taken in and stored. Notions of meaning are absent here, though this quality features in the other three conceptions: understanding, seeing something in a different way, and changing as a person (through learning).

Atherton (1999, p 78), however, offers a simpler classification of conceptions of learning, which he describes as being either additive or supplantive. He states that most learning consists in adding to one's stock of knowledge and skills - the additive concept. Supplantive learning involves material which replaces, or threatens, knowledge or skills which have already been acquired. It might also include, as Biggs (1987, 2003) maintains, new learning which triggered reminders of past failures, and, or, difficulties; but what is important is that, what was formerly 'known' has to be given up in favour of the struggle up the learning curve. Those students who view learning as the acquisition of knowledge or information as a commodity, tend to adopt surface learning approaches, whereas those who see learning as sense-making or comprehension, are disposed to adopt deep approaches.

A further approach, mentioned by Watters & Watters (2007, p 22), described as an achieving or strategic approach, is adopted by students who aim to get good marks and adopt strategies to achieve these as short-term goals. A motivational factor and a strategic factor thus exist within each dimension.
Posner et al (1982) offered prerequisite conditions for a learner's exchange of existing conceptions for new conceptions: firstly, dissatisfaction with currently held conceptions, and secondly, the new conception must be (a) intelligible, (b) initially plausible, (c) fruitful. The model, though very rational, neglects affective and social issues but was strengthened by inclusion of Toulmin's (1972) idea of conceptual ecology. This idea included the learner's epistemological commitments, metaphors, analogies, beliefs, connecting conceptions, and knowledge from outside the field (Strike & Posner 1992). The use of the word 'ecology' has been promoted by teachers of biology, for example, Watson (1986 p 340) writes about the "conservation of ecosystems of conceptions" and Kinchin (2000b p 12) refers to "learning within an appropriate teaching ecology" which he sees as the total teaching environment that is contributed to by teachers, students, and the 'conditions' in which they communicate. As I caution in Chapter 5 (Methods of Inquiry: Interpretation p130) an analogy, whilst it may be a useful source of insight, is not evidence that can confirm the truth of that insight.

The information processing model of learning (Novak 1958) assumes problem solving is a function of two traits: firstly, knowledge stored in the mind, and secondly, information processing capability. Ausubel's (1968) theory suggests these two processes are confounded in the process of new learning, where integration of new and old knowledge is a function of both the quantity and quality of cognitive structure organisation. This is Ausubel's assimilation theory which represents a significant shift because it spearheaded a cognitive revolution in learning, even though the ideas initially found more ready acceptance in Europe than in the America of their origin. At the core of this theory is the role of the subsuming concept in meaningful learning, which is an interactive role, facilitating movement of relevant information through perceptual barriers, and providing a base for linkage between newly perceived information and previously acquired knowledge. In the course of this linkage, the
The implications for curriculum design from primary science upwards, and for teacher education, are potentially extensive.

Support for the Ausubelian argument is found in the study by Munn et al (1992, p 11). In answering the question as to why some students taking courses designed for those with no prior experience, but who nevertheless value having previous knowledge, Munn et al (1992, p11) concluded that the students "like to relate material to that which they already know."; see also Merriam & Cafarella 1991, Cross 1981, and Knowles 1986. In the social sciences, existing knowledge can derive from life experience; in the natural sciences, this tends not to be the case unless the students...
have a job or hobby in that field. Therefore, any familiarity with the subject matter, even if gained many years ago, is seen as a distinct advantage.

Chinn & Brewer (1993) recognise five ways in which new knowledge can be related to old knowledge: (i) No new knowledge - Structured knowledge; requires that the mind starts as a clean slate (tabula rasa) onto which new knowledge is deposited. It is argued that when learning about phenomena that are 'invisible' in everyday life (for example, molecules or diffusion), then the student has no knowledge upon which to build. (ii) Fragmented knowledge - Structured knowledge; argues that naïve learners start out with a multitude of disconnected intuitions (p-prims), which are gradually refined to form a 'structured whole'. (iii) Simple core knowledge - Elaborated knowledge; learning simply elaborates and adds to core conceptions without changing them. (iv) Structured knowledge - Conceptually-consistent structured knowledge; a change in theory or understanding that does not require any change in explanatory concepts. (v) Structured knowledge - Conceptually inconsistent structured knowledge; this involves a major shift in underlying theories such that there is a fundamental change in key conceptions.

While this classification approach may have its applications within a general review of knowledge acquisition, some at least of the terms it uses (for example, 'simple core knowledge') cannot be given precise definitions. My study is designed to illuminate the response of an adult to new information, recognising that this may result in conceptual change.

Strategies to promote conceptual change may be based on cognitive conflict, where emphasis has to be placed on the design of appropriate interventions by teachers. These are aimed at 'loosening' existing cognitive structures, making them more amenable to restructuring at a higher level (Adey, Shayer & Yates 1989, p 241). Schwandt (1998, p 129) states that "one's constructions are challenged when one
becomes aware that new information conflicts with the held construction”. However, it cannot be assumed that any reconceptualisation will comply with the orthodox view, and evidence can be misinterpreted to fit existing theories (theory-laden observation).

3. BARRIERS TO LEARNING

Classroom observations suggest the existence of barriers to the development of adults as learners of science, these stem from the unique personal experience of some individuals. Some work has been done on this, though mostly not with reference to science, or with adults. Arising from a brainstorming between themselves is a list of eighteen barriers that emerged from the experiences of Boud, Cohen & Walker (1993, p 80). This led them to the working definition that, “Barriers are those factors which inhibit or block learners’ preparedness for the experience, their active engagement in it, and their ability to reflect rationally on it with a view to learning from it”. Concerning the types of barriers, Boud, Cohen & Walker classed these in terms of their origins as they saw them. Thus, external barriers can relate to: (a) the learning environment, namely, the larger personal situation and context of the learner. These external barriers correspond to the situational resistance of Atherton (1999, p 86) which include: administrative and technological failures, lack of pre-course information, course organization, venues and resourcing, credibility of tutor, for example, issues such as a male tutor teaching areas which have become preserves of ‘feminists’ etc., (b) social forces, which may include stereotyping, classism and cultural expectations, and (c) people, for example, censorial attitudes.

Internal barriers, corresponding largely with ‘ulterior’ resistance (Atherton 1999 p 86), and which stem from the unique personal experience of the learner, can include: (a) previous negative experiences, (b) accepted presuppositions about cognitive ability, (c) lack of awareness of one’s assumptions, (d) emotional state of the learner,
regarding the need to change (this component was explored in an interesting and seldom quoted text by More (1974) and may be an epiphenomenon i.e. a by-product of some other factor), and (e) established patterns of behaviour, risk and loss.

Stress and anxiety have often been used as interchangeable terms and observable symptoms would tend to support this practice. However, Catell (1963) points out that, the basic physiological anxiety pattern is not the same as that associated with stress, for example, anxiety affects metabolism and may cause a loss of weight. He also provides an interesting psychological example to distinguish stress from anxiety. When a difficult problem is tackled, stress symptoms are demonstrated, whereas anxiety is displayed when the person retreats or utilises other escape mechanisms. Catell also distinguishes anxiety from fear, as showing basically different physiological response patterns. Ausubel et al (cited in Singer 1968, p 95) defined anxiety as an "acquired reaction-sensitivity in individuals suffering from impaired self-esteem causing them to overreact with fear to any adjustive situation that contains a further threat to self-esteem". He separated students into low and high anxious groups, based on Rorschach Anxiety Test scores. No significant differences between the groups were observed on a mirror tracing test and a blindfold stylus test, but more complex tests showed that higher anxiety people perform less well than those low in anxiety. Moreover, those who scored low on anxiety tests perform more effectively under stress (in complex tasks) than under normal conditions. This is not the case with high anxiety individuals, who are less effective performers under stress – which can result from psychological, physiological and emotional origins (Selye, 1956).

Classroom observations (unquantified) have suggested to me that adults learning science constitute a higher-anxiety group than younger students, and it would be interesting to study, more extensively, the connection between anxiety states and performance in adult science learners.
To be a learner is to be an intellectual adventurer, but there are risks and costs. People tend to be, as Thaler & Sunstein (2008) suggest, present oriented - with a bias in favour of the status quo, but it is impossible to be ‘as we were’ as well as ‘as we will become’ at the same time. Yet, I found my students reluctant to abandon past known positions in favour of unknown future ones - if meaningful learning involves changing who one is, then they tend to avoid this. There is risk associated with change and, “as risks multiply, the pressure grows to pass oneself off as infallible and thereby deprive oneself of the ability to learn” (Beck 1992, p 177).

Interplay between external and internal barriers may be expected – thus barriers can be experienced as internal, but may arise from external influences in the past. The triggers for these barriers were found by Atherton (1999, p 84) to vary greatly from person to person, “issues which engendered great concern and resistance among some course members were no problem to others, who may however have been disturbed by quite different things”.

Certain topics were found to have a higher probability of provoking resistance than others, e.g. equal opportunities. But none of these barriers are specific to the development of adults as learners of science. Tytler & White (1996) identify the following as possible barriers to conceptual change: firstly, epistemological beliefs, secondly, a lack of domain specific knowledge, thirdly, specific problems associated with applying conceptions to new phenomena, and fourthly, past histories of conceptual application.

Classroom contexts, including the nature of interactions between teacher and students, may also be of considerable importance. Bentley & Watts (1987) recognised the consequence of requiring learners to have an active role - they find themselves having to reveal their thinking while, at the same time, having to be open
minded enough to change that thinking. This requires a highly supportive classroom environment, where learners' ideas are accepted by the teacher, and the risk of other learners ridiculing the thinking of any individual is eliminated.

Pintrich, Marx & Boyle (1993) drew attention to a paradox which exists for the learner. On the one hand, current conceptions potentially constitute momentum that resists conceptual change, but they also provide frameworks that the learner can use to interpret and understand new, potentially conflicting information. Learners have to embrace a certain amount of an Orwellian type of doublethink (holding two contradictory beliefs simultaneously and accepting both of them) in order to manage this paradox. Even learners' views can be a learning barrier, due to the discontinuity that is often assumed to exist between novices' and experts' knowledge (Larkin 1983, McCloskey 1983). Once this no longer exists, then careful analysis can uncover aspects of their knowledge that are continuous with, and may be used by, them to generate scientific understandings (di Sessa 1990, Smith et al 1993).

The factors that influence the evidence selection part of the process of knowledge acquisition represent biases and have been examined by Rosser (1994) and Klaczynski & Narasimhan (1998). Their conclusions point to a more biological explanation, with existing beliefs having the dominant influence because they are recognised and can be processed with less cognitive effort than unrecognised or conflicting evidence. This latter is, therefore, less readily assimilated into existing knowledge. Barker (2000 b) argues that, the effort required to understand 'hard' ideas can be too great, so ignorance remains bliss.

Salomon and Globerson (1987, p 623-634) claim that the gap between what learners can do, and what they actually do - the zone of proximal learning, can be narrowed down to a great extent by the notion of mindfulness. They define this construct as, "the volitional, metacognitively guided employment of non-automatic, usually effortful
processes”. Mindfulness, thus, reflects a voluntary state of mind and connects among motivation, cognition and learning. It is both a general tendency and a response to situational demands. Bloomer’s (2000, p 5) Further Education Development Association funded research illuminates transformations in young people’s relationships with, or dispositions to, knowledge and learning. He states that, “friendship groups, illnesses, student and parent relationships, and personal relationships, frequently had a bearing upon changes in young people’s educational values and attitudes to learning... these events... were partly the products of chance”.

It is relevant here to emphasise the distinction between the environment in which a learner learns, and the mechanism by which the learning of new material takes place. The importance of the former is not disputed, but this study focuses on the latter.

Pine and Messner (2000) found primary school teachers were struggling in science lessons, because pupils were reluctant to alter their beliefs about the way the world works. By the time they start school, children have created theories about a range of scientific concepts, and simply teaching them the right ideas about science is no guarantee they will give up their views. They will either disregard the evidence of experiments or simply misinterpret them to confirm their own belief. Thus, as Karen Pine states (Daily Mail 18.09.2000 p 31), “older students and adults still have wrong ideas about some aspects of science ... The challenge for teachers is not just to introduce children to new science topics but to help children unlearn their existing ideas”.

Pine & Messner addressed the question as to why children should develop their own naive theories about the world, if so often these ideas are incorrect or incomplete. They advance the explanation that,

prior to being exposed to any formal science education these naive ideas served to give the very young child some basic principles and heuristics for dealing with the world around him since most of the time they are proved
right. The fact that they are inaccurate, erroneous or incomplete also means that, whilst they may have been useful in an informal setting, they can actually hinder the child's ability to learn further about a topic in the context of more formal education.

Pine & Messner (2000, p 6)

Barker's (2000a) work seems to confirm this, her Royal Society of Chemistry report showing that, although children may be in possession of all the cognitive skills needed to answer questions, their naïve views may result in these answers being incorrect. Barker's Report, in addition to confirming that children tend to have naïve ideas, and that these ideas are resistant to change, further highlights the fact that children do not reason consistently, using a mix of sensory and logical reasoning. It seems that where matter is not visible, then sensory reasoning dominates. A consequence of this behaviour is that sensory reasoning about matter persists through secondary school ages, even though logical reasoning ability may be well developed and applied in, for example, mathematics. I argue that the findings of research work on children is relevant because it helps to explain how it is that adults come to have views that are so resistant to correction or, indeed, to change of any sort. Fritz et al (2000) were driven to recognise that prior knowledge (whether naïve theories or misconceptions) play a significant role in the new knowledge that these students will construct. And they, along with Ferrari & Chi (1998 p 1234) found that "faulty explanations are very resistant to change".

The suggestion here that naïve theories are synonymous with misconceptions, prompts a review of some of the terms used in the literature to refer to children's explanatory structures, prior to classroom instruction: (a) Misconceptions (Helm & Novak 1983) - a term currently used widely, for example, Barker (2000a) and Pine & Messner (2000), but can be argued to be erroneous, due to the a-priori disregard of children's ideas as being simply wrong. (b) Preconceptions - appears to be used
rather casually to describe ideas which might exist in the mind of an individual, before
the adoption of an idea currently accepted by the scientific community as orthodox
science, namely, a concept. (c) Alternative conceptions (Gilbert, Osborne &
Fensham 1982) - a term used to highlight commonalities in the cognitive structure of
many individuals. (d) Alternative frameworks - Driver (1981) uses the term to refer to
features of the mental organisation of an individual that were used for
conceptualising his or her experience of the physical world. (e) Synthetic models –
Vosniadou & Ionnides (1998) use the term to describe models constructed by
children in their attempt to reconcile the scientific information they receive, with
presuppositions and beliefs supported by their everyday experience.

Kaiser et al (1986) concluded that younger, pre-school, children were more
successful - because they were working without any preconceived theory, namely, it
is the having of a theory which leads to errors. Gadamer, however, quoted by Robin
Usher in a discussion on some neglected epistemological assumptions, argued
otherwise; that

"one's pre-understandings, far from being closed prejudices or biases (as
they are thought of in positivist empiricist epistemology), actually make one
more open minded because, in the process of interpretation and
understanding, they are put at risk and modified through the encounter with
what one is trying to understand. So rather than bracketing or 'suspending'
them we should use them as the essential starting point for acquiring
knowledge. To know, one must be aware of one's pre-understandings even
though one cannot transcend them"  
Scott & Usher 1996, p 21

Phil Sadler of Harvard University, in discussion which formed part of the television
programme Simple Minds (BBC2 1994), argued that, from a very young age, children
develop their own personal theories about how the world works. The mental models
they produce are based on their interpretation of the things they experience. Frequently, the models are incorrect, but are firmly held, because the thoughts are their own. In order to be able to predict what can happen in nature, however, you have to get beyond your misconceptions, because each one is a block to new learning. Sadly, most children do not get beyond their misconceptions and, to add to the problem, teachers can generate as many misconceptions as new "correct" explanations.

Conducting science experiments in a formal setting like the classroom, does not necessarily cause students to alter their misconceptions. Schauble (1996) found many children and adults still retained their incorrect beliefs. She noticed that participants refused to generate evidence, or entertain ideas, that did not fit with their existing knowledge, causing them to dismiss relevant evidence and cling rigidly to their current beliefs, even when they were wrong. Barker (2000a) confirms this, by claiming that the evidence indicates that one reason for the impact of current teaching of pre-sixteen year olds, is that students find it very difficult to 'unlearn' an idea. Gabel & Samuel (1987, p 697) note with concern that: "even after the study of chemistry students cannot distinguish between some of the fundamental concepts on which all of chemistry is based such as solids, liquids and gases, or elements, mixtures and compounds in terms of the particle model". Taber (1997) had reflected on this, noting that students never seem to be able to discard old ideas about chemical bonding but, instead, add new thinking to what was already there. He reflects that, for many the result of this addition is confusion and an absence of clear understanding. Taber concludes that, if students cannot unlearn ideas, then they should be taught the science they really need to know from the beginning.

The importance of ancillary skills to gaining understanding and knowledge is an area that may be worth investigating - it could be that the extent to which teachers appreciate the struggle with mathematics by learners of the physical sciences, is
underestimated. The extent to which this is, or is not, a barrier to learning science by adults offers scope for further exploration.

Boud, Cohen & Walker (1993, p 81) state that, "facilitation of learning is essentially about helping learners deal with their barriers to learning. Helping them to conceive of a barrier to learning as susceptible to influence rather than an inherent deficiency can be a personally empowering step". They identify four steps which can help with the alteration or transformation of barriers: (i) acknowledgement of existence of barriers, (ii) identification by name or description of barriers, (iii) examination of the origins of barriers, in order to see how they operate, and (iv) working with barriers using strategies which may be either confrontational or transformative.

The removal of barriers to learning that have become deep seated through being learned over many years, especially where some degree of emotional impairment has occurred, is a specialised study. Though closely linked to successful learning, it is beyond the scope of this thesis.

The term 'unlearning' has relevance to this study, though it has nothing to do with Plato's paradox of some things being unlearnable because they must be known before any process of learning could be undertaken. It is also not synonymous with forgetting, from which it will be distinguished later in this chapter. Unlearning is a term used by Brew (in Boud, Cohen & Walker 1993, p 88) to describe what happens when our 'world view' is changed, and cannot be reconstituted in its original form, because new experiences have transformed existing understanding into something else. The destruction of previous learning will be triggered when a set of anomalous ideas cannot be incorporated within a framework of understanding, and so a conceptual reordering takes place. Brew likens the process to a Kuhnian paradigm shift, and says it can occur to both cognitive and experiential knowledge. Brew considered the assumption that, an accumulation of experiences leads to, or
parallels, the accumulation of knowledge. She found that, for herself, whilst there was an appearance of a progressive deepening of understanding of issues that she was considering about herself which was fed by a strong desire to know more, she was also conscious of a strong desire not to know, or to not know. Brew then discovered that she had a repertoire of mechanisms and procedures for preventing her finding out what she did not want to know. Although some of these things she did not want to know were derived from her personal history, others she found to be embedded in the culture of academic inquiry; for example, traditional academic inquiry de-emphasises the role and value of human subjective experience. Brew argues that the implications of this suggest that the learning we do from experience, can be a way of avoiding what we need to, or should, learn.

There is a difference, of course, between the pursuit of self-knowledge referred to above, where what we learn is what we learn, de facto, not what we choose to learn, nor maybe what we might liked to have learned, and learning science where situations are planned in order to bring about specific learning. However, unlearning, seen as triggered when evidence necessitates a conceptual reordering of the whole or a part of one's world view, is a process that needs to be understood and used by all learners.

In contrast with unlearning, are the related processes of forgetting and obliterative subsumption. Ausubel (1968) introduced the term 'subsuming concept', to cover the interactive role of facilitating movement of relevant information through perceptual barriers, thus providing a base for linkage between newly perceived information and previously acquired knowledge. This interactive process, between newly learned material and existing concepts, is the central core of Ausubel's assimilation theory of learning. Subsuming concepts may become established in the course of meaningful learning, or may become obliterated in that process.
'Forgetting' has an everyday meaning as the failure to recall something, and a specific technical meaning where it describes failure to recall after rote learning. The diagram in the 'Tools' section of Chapter 5 shows the relationships between forgetting and obliterative subsumption. Novak (1998, p 60) refers to studies which show that substantial forgetting occurs in a matter of hours for nonsense syllables, a matter of days for poetry and story passages, whilst for science or history retention drops to a fraction of original learning in a matter of weeks. Some information, especially if it has been rehearsed extensively, can be retained for months or years. In Ausubel's theory, variation in amount of recall depends primarily on the degree of meaningfulness associated with the learning process, although Novak emphasises the shorter periods of retention when contrasting rote learning with meaningful learning. However, the point he is trying to make is that there is a residual enhancement of cognitive structure with meaningful learning, which is not present following rote learning.

An obstacle to learning that I had noticed with children of secondary school age when learning science, and which appeared to be equally prominent with adults, concerns the ability to comprehend texts relevant to the topics being studied. I shall refer to my experiences with a pre-Access to Higher Education course, during the week that the National Year of Reading in September 1998 was being launched. I wondered, some time later, whether the publicity associated with this event had alerted my mind to the observations I was making. There had been a poor response to the first allocation of home study, and one student was courageous enough to say she didn't understand the work. I responded by going through the work with the group, word by word, and began to see that, although they knew some science, they could not effectively comprehend what they had read from the text book. Their difficulties were confirmed at the first practical session, where quickly it became obvious that some of the students were unable to read instructions meaningfully. Their mannerisms
suggested that they had developed the habit of watching what other students did but, in this situation they were finding this difficult because they were a group who were mostly new to each other, and were as yet unsure of who could do what.

Written language does not have all the supporting cues (stress, intonation, tone of voice, gestures, facial expressions and social context) that accompany spoken interactions. Whilst it is often the case that once children have learned to decode words reasonably efficiently, comprehension will follow automatically, there is not always a high correlation between word recognition ability and reading comprehension ability. This may be because an individual is so preoccupied with word decoding that he or she may not have the cognitive capacity to carry out comprehension processes at the same time. In addition, the rapid loss of information from short term memory makes it difficult for very slow readers to hold information from earlier in a sentence so that they can relate it to what comes later. The problem can be compounded by the reader's belief that the point of reading is 'getting the words right', and they may not connect this activity with deriving meaning from a text if it were read to them.

The Gunning Fox Index enables texts to be compared for readability, and the steps for the calculation are given in Appendix 7. The most important factor in this formula is the length of the sentence and, although it would always be possible to get an easy readability rating by using very short sentences, this would tend to produce writing that sounds like a children's book. Another key factor is the intellectual span of attention of the reader and, hence, in matching the 'unloading rate' of information to this span. I could not, for example, give the following to my pre-Access to Higher Education class simply because they lacked the expertise to decode the technical language: 'Crystals were grown as hexagonal plates, up to 300microm. x 100microm. in thickness by vapour diffusion of 2.1 M-ammonium sulphate, in trisacetate buffer
(pH 7.0), in the presence of 0.01M-Mg'. However, the information could be communicated to them by re-writing it as several sentences. They were completely lost by the following (unattributed) passage, where the important information is spread very thinly:

'In recent years, since the Second World War, a proliferation of the sizes and types of aluminium conductor utilised in overhead electric power lines has occurred. An attempt is made in this article to provide a guide to the range now available to the designer of lines. For super-tension transmission lines, increasing voltage, heavier currents, and longer lines have introduced demands for conductors having greater diameter, larger cross-sectional area, and increased strength, the emphasis on one or other of these factors being variable in accordance with the function for which each particular line is erected.

The production of phase conductors having a high degree of capacitance and a lower level of reactance can be achieved by the utilisation of bundles of two, three and four conductors, which practice usually reduces radio influence and corona loss to levels which are acceptable almost regardless of the route of the line. It is regrettable, however, that special problems are presented by conductors in bundle form in climates of an extreme nature, such as at elevated altitudes or where ice loads or heavy winds are prevalent; and in all environments considerable accentuation of the mechanical problems presented by bundles occurs when the sub-conductors in the bundle are three or four in number rather than two. Thus, in spite of new developments in respect of bundling, a trend towards large diameter conductors continues to be evident.'

They digested this more successfully when I presented it as:

'This passage is a guide to the sizes and types of aluminium conductor
available to the designer of overhead power lines. In recent years, the choice has widened. Now that we are concerned with super-tension transmission lines, increasing voltages, heavier currents, and longer lines, we need conductors with greater diameter, greater cross-sectional area, and greater strength. Which of these factors is most important depends on the function of the line being erected.

Bundles of two, three and four strandings can be used to make phase conductors with higher capacitance and lower reactance than single conductors, and with acceptable levels of radio influence and corona loss. But bundle conductors set special problems in extreme climates, for example, where there is ice or high wind, and the mechanical problems presented by bundles are always worse where there are three or four sub-conductors in the bundle rather than two. So, large-diameter conductors are still preferred to bundles.'

'Unloading rates' do not seem to have been quantified by formulae in the same way as readability, although some of the more complex formulae dealing with this do take account of the number and frequency of technical terms. But I had a suspicion that I was attempting to fine tune something that may not be fine tunable if the students had never been taught to interrogate text in an active way. It did appear that they seemed to imagine that, so long as what they read is vaguely sensible and relevant, it will somehow be absorbed or, if not, that is because they are too dim, and so there is nothing they can do about it. But the kind of passive reading that was all they seemed to know, must result from teachers, like myself, setting homework accompanied by instructions similar to: 'make notes on this section' - instructions which are analogous to giving students a general instruction to do an experiment, without any indication of the particular purpose of the experiment, or of how to go about doing it. They needed to be directed to a more active and interrogative kind of
reading, and a practical session would provide a suitable opportunity for this. I gave
the students a piece of text which I judged would be understandable, plus a work
sheet:

The Text

Here is another way of finding out about charges. You have four strips of
plastic. Two are cellulose acetate (the clear ones), the others are polystyrene
(the opaque ones). Rub one of these strips with a duster and balance it on
the watch glass. Now bring it near a rod of the same kind which you have
rubbed with the same duster, and observe what happens as you bring the
ends near each other. Do they attract or repel? Each strip has obviously
been given the same charge because they were both treated exactly the
same way. What do like charges do to each other?

Now repeat the experiment using two strips of the other material. Do they
attract or repel each another? Does this agree with what you found in the first
part of the experiment?

Now rub a strip of one material and balance it on the watch glass, and bring
up to it a strip of the other material, which you have also rubbed. What
happens this time?

Can the charges be alike? If they are not, they must be opposite or 'unlike'.

What can we say unlike charges do to each other?

The Worksheet

1. First read the complete passage on the sheet to the end.

2. Decide how many experiments are described.

Draw a line across the page between each experiment, and number the
experiments.
3. (a) For the first experiment, underline in pencil the names of any pieces of apparatus you will need.
   (b) Put a circle round the words which tell you what to do.
   (c) Underline in red any questions you see.
4. Do the first experiment.
5. For the second experiment, again underline the pieces of apparatus, then circle the words telling you what to do, and underline questions in red.
6. Do the second experiment. And so on, until you have finished all of the experiments.
7. Finally, look again at the questions you have underlined to check that you have answered them.

This was a successful exercise and yielded an important piece of information in the form of a question: 'Can we actually mark the handouts?' The discussion which followed revealed that teaching not to annotate texts had been widely effective. The reading of scientific texts is a specialised technique, and not the natural activity I had come to assume it is after many years of familiarity with them, requiring skills additional to those needed for general reading. Further, I was accepting a professional obligation to teach the necessary techniques and to provide suitable texts. However, Lunzer & Gardner (1979) found, from a survey, that the pre-processing of information for pupils in the form of notes and worksheets by teachers does not make the problem of textbook difficulty go away.

That the majority of students do not use texts effectively is no reason to abandon them - it may be more profitable to try and change the approach to using texts, rather than trying to change the students, or change the texts. One attempt I made to do this succeeded only in causing frustration among the students. I had verbally outlined an experiment and reached a stage where I thought they understood what to do. Then I handed the instructions in scrambled form and told the students to
reorganise the list into meaningful order before proceeding.

The Scrambled Text:

To measure the heat given out per second by a Bunsen burner flame
Set the Bunsen burner onto a blue flame
Record the new temperature of the water
Measure the mass of the beaker plus water
Calculate the temperature rise of the water
Start the stop-watch
Calculate the number of joules of heat received by the water, assuming that
the specific heat capacity of water is 4200 J/Kg°1 K°1
Place the beaker on a tripod with a gauze
Measure the mass of a clean dry 250cm°3 beaker
Calculate the number of seconds for which the water was heated
Stop the stop-watch and note the reading
Place the Bunsen burner under the beaker
Add approx. 50 cm°3 cold water to the beaker
Calculate the number of joules received by the water each second
After about 5 minutes, remove the Bunsen from under the beaker
Calculate the mass of water in the beaker (in kg)
Take the initial temperature of the water

The exercise caused more difficulty than I had anticipated, much time was lost and, in the end, I had to get some copies made of the correct order and distribute these, but, by now, there was insufficient time to get all the work completed, hence the frustration.
To measure the heat given out per second by a Bunsen burner flame

Measure the mass of a clean dry 250cm³ beaker

Add approx. 50 cm³ cold water to the beaker

Measure the mass of the beaker plus water

Take the initial temperature of the water

Place the beaker on a tripod with a gauze

Set the Bunsen burner onto a blue flame

Place the Bunsen burner under the beaker

Start the stop watch

After about 5 minutes, remove the Bunsen from under the beaker

Stop the stop-watch and note the reading

Record the new temperature of the water

Calculate the mass of water in the beaker (in kg)

Calculate the temperature rise of the water

Calculate the number of joules of heat received by the water, assuming that the specific heat capacity of water is 4200 Jkg⁻¹ K⁻¹

Calculate the number of seconds for which the water was heated

Calculate the number of joules received by the water each second.

Other reconstruction exercises were more successful, as were text marking and text analysis, and I had learned that the fault is often as much due to the writer as to the reader. Thus, I might once have written, ‘Human beings hope to survive, and be comfortable, on this planet for a length of time that far exceeds the duration of all fuel reserves. Physicists, therefore, are now applying themselves to the question of whether science can possibly harness alternative sources of energy’. Whereas, I would now write, ‘We hope to survive in comfort on this planet for longer than fuel reserves will last. This is why physicists are always asking, ‘Can we harness other
sources of energy?'

However, this does nothing for the level of literacy of learners which has to be increased if they are to read successfully for learning in science. Understanding a text results in a mental representation of the state of affairs it describes, and a number of skills are needed to construct such representations, for example, inferential skills, meta-linguistic skills and the ability to understand text structure.

Yuill & Oakhill (1991), working with children whose comprehension is poor in relation to their word recognition ability and chronological age, have shown that such children differ from those with good comprehension, in their ability to make inferences and integrate information from different parts of the text, and in their meta-linguistic skills. They could be characterised as superficial readers - they seem to process text fairly literally, without deriving the meaning of the whole. Such children do not have general memory problems, although they do have a deficient working memory capacity. Since working memory is important in making inferences, and in the construction of a meaningful representation from a text, it is not surprising that those with poor comprehension are deficient in these skills. Those with poor comprehension, like young children, do not have a clear awareness of what comprehension is, and when they have been unsuccessful they may fail to realise that they have not understood a text properly. There is evidence that their problems might arise, at least in part, because they fail to make use of comprehension monitoring strategies (Garner 1987) and, once again, working memory may play a part in such processing. In general, people who are poor at understanding written text, but who do not have any problems at the level of single words, are also poor at listening comprehension, and even at understanding and narrating the main point of a picture sequence. Thus, comprehension skills do not necessarily develop automatically, and so my efforts may not be successful in trying to encourage students to become more active in their relationship with text, however hard I try.
In teaching science it is important to be aware that scientific knowledge is not simply a 'collection of facts' but a 'way of thinking'. There are difficulties in learning scientific concepts and making them into ways of thinking about the world. One of these difficulties is making distinctions that we would not ordinarily make in everyday life, such as the distinction between temperature and heat, as the following example illustrates. Although the temperature of two ice cubes is the same, even if one ice cube is twice the size of the other, the effect they have in cooling a drink is different. At least one of my students thought that the larger ice cube had a lower temperature than the smaller one as a consequence of the fact that they had different effects in their capacity to cool a drink. Another difficulty can be that scientific concepts often require reasoning about non-perceptible aspects of the physical world; a good example is the particulate nature of matter. We deal, in everyday life, with a world that is continuous, in which objects are solid and undivided. Yet to understand many of the changes that we observe in the world it is necessary to develop a way of thinking about the world that describes our solid objects as bundles of particles, namely, discontinuous elements that are kept together in some way. Piaget and his colleagues (Piaget & Inhelder 1974) were pioneers in the investigation of children's understanding of the particulate nature of matter, and set out a pattern of investigation by pointing out that, it is when children have to understand change that they come to 'invent' an atomic theory about the world.

A major source of difficulty with my students is that they have already developed some knowledge about the world, and this knowledge differs from that which I am aiming to teach in the classroom, both with respect to the different conceptions they have and the formal characteristics of the concepts used. Thus, whereas scientists strive to explain the largest number of phenomena with the smallest set of assumptions, a principle known as parsimony, in everyday life we do not strive to achieve this principle. Vygotsky (1978) has described this difference between
everyday and scientific concepts by suggesting that we learn scientific concepts from the general to the particular, but we learn everyday concepts from the particular to the general.

Studies of the solutions to problems by both experts and novices made by Smith & Good (1984) identified the differences between those experienced in the methods of science and those new to them. These included: (i) a tendency among the experienced to treat problems as tasks of analysis and reasoning, rather than trying to remember algorithms that would lead to solution, (ii) a tendency among experts to use a knowledge development approach that required structuring the information obtained, and testing possible conclusions against new information, and (iii) a tendency among experts to have and use accurate knowledge.

All these points are both important and relevant, because they highlight the point that learning the way of thinking that is science, is more than being able to read science, although this is where the process must start, and the first hurdle any learner must conquer. Although 'scientific literacy' is a term which some have coined as a scientific core skill requirement, what the term actually means and how it overlaps with the capability to actually 'do' science, seems to lack a broad consensus among users. Wolf (2008) claims that it is an astonishing feat to be able to translate the squiggles packed on to a page into a vast array of images in one's head. She reminds readers that reading is only a few thousand years old – too new to be encoded into our genes. Therefore we have to learn it the hard way.

4. SUMMARY

This chapter has considered, briefly, some contemporary ideas concerning learning in general, but particularly with learning viewed in terms of changing concepts. Some aspects of resistance to conceptual change were looked at, and my experiences with
learners who encounter difficulties with reading science texts have been included. Some of the research has been carried out with younger children (by, for example, Piaget). In the next chapter issues about learning science, particularly as they relate to adults, will be considered in more detail.
CHAPTER 4

ADULTS LEARNING SCIENCE

1. INTRODUCTION

This study is concerned with adults learning science, and in the first part of this chapter some of the more relevant aspects of the term 'adult' are explored. It will be seen that adults are not the simple blank sheet that children, apparently, present, and that previous experience of adult learners is not the chronic disadvantage it used to be seen to be. What may have been dismissed as handicaps which creep up with age, are more likely to be a natural resistance to peremptory and authoritarian methods of teaching.

The second part of the chapter considers some of the issues relevant to the study that relate to learning science. It may not be easy to find a consensus regarding a definition for the word 'science', but the approach used by Waddington (1948, in his Forward p x), that science is the organised attempt of mankind to discover how things work as causal systems, covers the activities referred to in this thesis. It is the pursuit, by characteristic methods, of this context independent goal to elucidate the laws of nature that marks a project as scientifically significant. School science can sometimes appear to be presented as a box of tricks which work; with adults, and arguably with children also, it needs to be presented more as an attitude to the world, a way of living. This section of the chapter does not explore either issues of curriculum, or strategies of teaching science, as both of these are outside the scope of the thesis. Rather, it tries to focus on issues relating to the nature of what has to be learned, and some of the problems encountered by adults in dislodging existing beliefs when contrary evidence is presented.
1. ADULTS LEARNING

Because the word 'adult' can be used in different ways, it is necessary to conduct a brief survey of some of these uses as a prelude to a study of learning by adults. Thus the term can refer to a stage in life after a predetermined age, or it can represent a status in society. In a sociological context it could describe a subset of people (as are children, for example), or a set of culturally determined ideals and values. The UNESCO description (UNESCO 1976) suggests that adults are persons regarded as adult by the society to which they belong. It clearly categorised the state of 'adulthood' as a social construct and, as such, it is context dependent, with variations within areas, class, culture, and era. The care that must be exercised in reading the work of other researchers is illustrated by, for example, Johnstone and Rivera (1965, p 26), an adult is "anyone either age twenty one or over, married, or the head of a household". Merriam and Caffarella (1999, p 393) suggest that people are adults "because they have assumed responsibility for managing their own lives". Aspin et al (2001, p xvii) believe that adulthood is seen as the "point when individuals may be regarded as having attained a degree of autonomy".

The significance of these different perspectives assumes importance when one is considering adulthood and education. Thus, Rogers (1992 p169-178) may be accurate in his assumption that in most societies an adult is someone who has a measure of internalised independence in decision-making, and is no longer under another person's authority. However, such views may carry, or may have carried, implications where women are denied many of the expressions of adulthood, and in situations where men live within an extended family where their role does not include much in the way of personal responsibility. Yet there would not be dispute over describing these people as adults. Rogers (2003) surmises that adulthood is confirmed by reference to childhood, and that there are three main characteristics of the construct of adulthood as contrasted with children. The first is maturity, namely,
that they have developed their potential more fully than children have. Secondly, adults have more autonomy - they have responsibility for themselves and, or, for others, this arising from the greater independence they have than do children. Thirdly, adults have a greater sense of perspective in relation to the world, not being the centre of the world that children often seem to think themselves to be. For all this, a young person who is earning his or her own living is not necessarily an adult. They are only so when they can demonstrate their possession of the standard of development, maturity and expertise, and the independence of action, which traditionally accompany adulthood within their own culture. These are the qualities which attract recognition of the state of adulthood by society at large. In medieval times the boundaries between childhood and adulthood were blurred; at Winchester School, the first and most generously endowed independent school, relatives of the founder could stay until they reached the age of twenty five years (Orme 2006).

All of the learners who have been involved in the field work for this study have had post school employment experience (see Appendix 5 for an indication of typical age profile). All of them are accustomed to responding to their own learning needs through self direction, and some may have participated in vocational education.

The more traditional kinds of learning theory dealing with internal mental processes are based on the assumption that, learning occurs by means of certain innate mental mechanisms that have been generated throughout the history of our species' struggle for survival (Simonsen 2005). The general assumption is that, in general, these mechanisms are at the disposal of any normal human being, although the ability to practise them fully only emerges gradually during the years of childhood. More recently, learning theories have emerged which feature social processes (Gergen 1991), an example being that of social constructivism, where age certainly influences the learning processes, the reason being that the ways in which the
individual is involved in social processes, are strongly influenced by age. There is, however, no one definition, model, or theory that explains how adults learn, or how the learning process is facilitated.

Until the mid twentieth century what was known about adult learning was embedded in studies by behavioural and cognitive psychologists. These were studies which focused on problem solving, information processing, memory, intelligence and motivation. Much of this work was conducted in laboratory settings, and interest centred on how advancing age affected the learning process. Thorndike et al (1928, p 178) reported the results of adults being tested in a laboratory, under timed conditions, on various learning and memory tasks. The authors concluded that adults between twenty five and forty five years of age, could learn "at nearly the same rate" as twenty year olds. Further work found that, when the time pressure was removed, adults up to the age of seventy did as well as younger people. An implication of this is that if adults do not perform well, the cause should not be assumed to be linked to their chronological age.

By the mid twentieth century adult educators were considering how learning in adulthood could be distinguished from learning in childhood. This resulted in the identification of three features: the first is andragogy, a European concept introduced to North America by Malcolm Knowles in 1968, to distinguish adult learning from children's learning (pedagogy). Andragogy is characterised by a set of assumptions that the adult teacher has about the adult learner (Tennant 1988), videlicet: Firstly, there is a development of the self concept from dependency to self direction. Secondly, adults have accumulated experiences and these can be a rich resource for learning. Thirdly, in children, readiness to learn is a function of biological development and academic pressure. In adults, readiness to learn is a function of the need to perform social roles. Fourthly, children have a (conditioned) subject centred orientation to learning, whereas adults have a problem centred orientation to
learning. Fifthly, for adults, the more potent motivators are internal.

1. Andragogy

Using these assumptions as a starting point, Knowles then specified the skills, processes and techniques of helping adults to learn. His scenario for adult learning has been critically analysed by Griffin (1983), Jarvis (1984), and Brookfield (1985), who have highlighted the gap between theory and practice, the untenable nature of the andragogical assumptions, the lack of supporting evidence, its conceptual limitations, and its ideological impact. Some observations supported by classroom experience are given below: (i) Self-concept - Knowles (1990, p 58) suggested that, "as a person grows and matures his self concept moves from one of total dependency to one of increasing self directedness". I am not convinced that everyone aspires to self dependence, and it is possible that this proposition reflects the ideology of American individualism; certainly it was written by a Westerner who had attained a certain degree of independence. (ii) Experience - here Knowles (1990, p 59) claims that, "as an individual matures he accumulates an expanding reservoir of experience that causes him to become an increasingly rich resource for learning, and at the same time provides him with a broadening base to which to relate new learning". The assumption here is that experience is chronological rather than contextual. Classroom observations suggest that growth in experience need bear little or no relationship to age, but just to the biography of the one who experiences. (iii) Readiness to Learn – Knowles (1990, p 60) claims that "as an individual matures, his readiness to learn is decreasingly the product of his biological development and academic pressure and is increasingly the product of developmental tasks required for the performance of his evolving social role". He further suggests that pedagogy assumes that, children learn what they ought to because of their biological development, whereas adults learn what they need to learn in order to cope with the exigencies of their daily living. Yet adults do seem to
learn because of their biological development, for example, in old age they learn
strategies to compensate for reduced physical powers; so, again, I wonder whether
Knowles correctly analysed the process of biological development. (iv) Orientation
towards Learning - Knowles (1990, p 61) claims that "children have been conditioned
to have a subject centred orientation to most learning, whereas adults tend to have a
problem centred orientation to learning". He does not present this distinction as a
'natural' difference between adults and children, and one wonders whether if children
were not conditioned to be subject centred, they would 'naturally' be problem
centred. Implicit in this assumption is the idea that, adults require immediate
application of their learning, whereas children do not. I think Knowles could be taking
the fact that, for children, postponed application of much of their knowledge is
inevitable, whereas adults may be likely to have more opportunity to apply knowledge
soon after acquiring it; Knowles presents this as 'natural', arising from the differences
in chronological age. It could be argued that adults have a greater capacity to
tolerate postponed application of knowledge because they are able to conceptualise
time over a different scale. (v) Motivation to Learn – the Knowles (1990, p 57) model
distinguishes between internal (concerned with self-esteem and self-confidence) and
external motivators (concerned with external pressures), and argues that, for adults,
the more potent ones are internal. Tennant (1988, p 23) is very clear in his view on
this, "the proposition that internal motivators become more salient with maturity has
no support in the literature on life span developmental psychology."

Knowles' assumptions led to a debate in the journal Adult Education (and elsewhere)
which Elias (1979) initiated and to which McKenzie (1979), and others, responded.
This forced Knowles to revise his distinctions and reflect this in a new edition of his
work (Knowles 1980) - the subtitles changing from 'pedagogy versus andragogy' to
'from pedagogy to andragogy'. The substance of the change was the admission that,
adults could learn both pedagogically and andragogically, but he held to the belief
that there were different forms of teaching and learning which had a tendency to occur chronologically. Jarvis (1994) very clearly summarises the falsity of relating andragogy and pedagogy to biological age, whilst acknowledging that there is a possible, but not necessary, association; although epistemological, ontological and organisational considerations are omitted. Jarvis points out that an adult's experiences are contextual rather than chronological, so what is important are the levels of experience of the learners. However, the actual distinctions drawn between the two types of teaching and learning are not necessarily incorrect, and may be relevant to the differences between initial and continuing vocational education.

Useful though Knowles' work was, however, it was still a non-developmental concept of adulthood – it having been assumed that adulthood is a non-developmental period in life. Thus the model of adult thought was the same as the model of fully matured adolescent thought. Piaget (1972), although he never studied adults, did predict that certain changes would take place in formal reasoning during adulthood, because an adult's experiences in work and social relationships would necessitate adaptations in the adults' thinking processes. This concept, of thought becoming progressively adaptive through interaction with adult life experiences, is central to much of the theory which has emerged in the study of adult development.

2. Self directed learning

The second feature said to distinguish learning in adulthood from learning in childhood, is self-directed learning; learning that occurs as part of an adult's everyday life that is systematic, yet does not depend on an instructor or a classroom. The impetus for this model of adult learning came from Tough's (1971) research with Canadian adult learners, though the initial descriptions have since been extended to include opportunities for learning found in one's environment, including chance occurrences. Brookfield (in Galbraith 1991, p 5) comments on the element of authority dependence in many adults' socialisation, and which predisposes them to
regress to childlike behaviour when entering an adult classroom. He advises that adults returning to formal education should not be seen as "lions of self-directedness roaring to escape the leash of teacher and institutionally imposed constraints". Anxiety and insecurity are to be expected, to varying extents, in all adult learners.

3. Transformational learning

The third feature is transformational learning, which is about the cognitive process of 'meaning making', rather than focusing on the learner. It is dependent on adult life experiences, and a more mature level of cognitive functioning than is found in childhood. Mezirow (2000) is considered the primary architect of transformational learning, which claims the learning process is initiated by a disorientating dilemma. Merriam (2005, p 45) describes this as, "a life experience that cannot be accommodated by one's existing worldview". Such an experience leads the adult to examine, and critically reflect on, the assumptions and beliefs that have guided meaning in the past, but are now no longer adequate. From an examination of current beliefs, the learner moves to exploring new ways of dealing with the dilemma and, in dialogue with others, tests out new assumptions, understandings, and perspectives. The new transformed perspective is more inclusive and accommodating than the previous perspective. The involvement of other people is a requirement for transformational learning, and is one of the ways it may be distinguished from the 'active' learning described by Rogers (1989) - where an internalisation process occurs in which the learning becomes identified with the learner. Rogers gives an example relating to British Rail which, in the 1960's had to turn steam locomotive drivers into people who understood something about electricity, and who could do simple fault finding when driving diesel electric locomotives. British Rail's first attempt, by giving lectures on the subject of the principles of electricity, had a very high failure rate. E. and M. Belbin (1972) devised, and introduced, a series of circuit boards of increasing complexity, the first board
carrying only a battery, ammeter and switch. Trainees were supplied with a bulb, bulb holder, a more powerful battery, two small electric motors, wire and clips. Written instructions directed them as to which pieces of apparatus to assemble with which, and invited them to experiment in various ways with the apparatus, then to observe and draw conclusions. The trainees came to see, through their own observed experience, that an electric circuit must have an undisturbed path, before current can flow from one pole of the battery to the other. The last board of the series simulated the power circuit of a diesel electric locomotive. The Belbins called their method, the Discovery Method (the name giving an immediate reminder of the Dewey approach), and it was considered an important contribution to wider theory because it revealed that process (activity) matters more than the subject. The distinction illustrates a trend to move learning beyond a preoccupation with the individual learner, a trend towards contextualising learning, as, for example, in the approach to adult learning known as situated cognition. This posits that learning is context bound, and is most effective and meaningful in situations where cognitive processes are required, rather than in the simulated activities that are typically found in educational institutions.

The issue of context as it applies to learning – both in science and in other fields of knowledge – has been studied with respect to women's learning. Barr and Birke's (1994) findings concerning women's perceptions of science highlight the ways in which groups, rather than individuals, are important for learning, and the need for science education to draw on approaches to curriculum development which have emerged in recent decades, before these become lost in the strong moves towards vocationalism that exist at present. Though Barr and Birke acknowledge differences in attitude which they related to varied life histories – due, for example, to age, social class and ethnicity, they noted (Barr and Birke, 1995 p123) consistent themes within similar groups, for example, a refusal to accept the notion of 'scientific facts' which
the authors’ took to indicate a resistance to accept the concept of objective knowledge – though it might equally be linked in some way to the idea of ‘authoritative knowledge’. Some twenty years ago Belenky et al (1986) identified five categories of knowledge construction relating to women's learning; from silence – where women are passive and what they know is defined by others, to constructed knowledge - in which women are active creators of their own knowledge. Yet science teaching, from the style and language of texts to laboratory design, is still criticised repeatedly for being stuck in a patriarchal framework, and this has been used to explain the under representation of women in academic and industrial employment. There seems to be little recognition that, if women are saying that science is not for them, then it could be saying something about science itself as well as the processes of science education. My own experience, based on delivery of a variety of courses in which women tend to predominate – broadly supports the findings of Barr and Birke, and that when the fears and prejudices that seem to originate early in secondary education are broken down, women find science stimulating and rewarding, and achieve as well as men on the same courses. Rich (1979 p. 240) encapsulates this rather well by suggesting that the most important thing a woman, and especially a woman returning to education as an adult, can learn is that she is capable of intelligent thought.

Riegel (1973) accepted that formal logic - on which model Piaget's theory was based, offers a model for certain types of adult thinking, but argued that the nature of adult thinking was potentially more complex. Riegel's theory draws on a system of dialectic logic, namely, reasoning, wherein ‘contradiction’ rather than ‘identity’ is the most essential feature. According to Riegel the most effective adult thinking is not that which provides immediate answers, but that which first discovers the important questions and, or, poses the important problem. Therefore, it is not primarily a matter of eliminating contradiction, but of tolerating it and, thus, allowing for new
questions and problems to emerge. This hypothesis, that mature adult thought is qualitatively different from the thought of adolescents, has led to more serious study of the potential for cognitive development, and the nature of thought, during the adult years. It seems to me that, Riegel's hypothesis is a development of an idea in which 'doubt' is identified as the motive for thinking and 'thought' is characterised as appeasing the irritation of that doubt.

Researchers in many fields seem driven by a 'Linnean' mission to classify and subdivide into categories the subjects of their study with greater or lesser utility, and the activity of learning has not escaped this. A variety of approaches has been used and accounts can be found in Jarvis, Holford and Griffin (1998) as a full description of possible types of learning is outside the scope of this thesis. The concept of reflective thinking or reflective learning is, however, used widely and referred to by Piaget (1967) as being present in adolescence, though he does not suggest that the facility continues to develop through later life. Moshman (1979) has demonstrated that meta-theoretical thought (thinking about one's own theories), develops subsequent to formal operational problem solving, but, whether this ability is necessary to, or follows from, mature reflection, is also not clear. It would be interesting to explore whether reflecting on how we think about our environment and experiences is a necessary prerequisite to asking questions, discovering problems, and to contradiction becoming a basis for thought.

There is evidence (Labouvie-Vief 1980) that adult development is achieved by the loss of certain competencies, in order to gain more adaptive ones. Piaget's biology of knowledge, which von Glasersfeld (1970) was aware of, also characterised learning as an adaptive function, and Plotkin (1994) further developed the concept of knowledge as adaptation. Also, according to Thelen and Smith (1994, p 313-314), "infants come into the world with a rich set of adaptive biases, epigenetically
acquired, but having a strong selective value....". Schaverien and Cosgrove (1999 p 1227) state, "no longer can learning be considered to occur by means of instruction, but rather by means of selection". Their paper refers to learning per se, although many of their references are to child development.

Schauble (1996) points out that, adults’ experimentation strategies are generally superior to children’s - even when the adults had little formal education and no science instruction when at school. She also draws attention to the fact that little is known about the differences in how children and adults learn in the context of self-directed experimentation, an observation which seems to imply that such differences do exist. Schauble does, however, identify further relevant factors: firstly, the greater proportion of valid inferences made by adults may be due, in part, to their tendency to be both more systematic, and more comprehensive, in their experimentation. Secondly, the differences in the structure and content of their knowledge bases account for some observed differences in the reasoning of adults and children. Thirdly, adults possess a variety of heuristics that appear to serve as a check on reasoning biases. Children may be less likely to have, or to use, such heuristics. Fourthly, there is evidence for the existence of very early precursors, competencies, errors, and biases which persist, regardless of maturation, training and expertise.

Simonsen’s summary (in English, 2005) gives a useful general overview of the differences in biological age and learning, and this is included in order to conclude this section of the chapter. The overview being that children want to capture their world; the characteristics of childhood learning are that it is uncensored, confident and must be done with the support of adults. Young people want to construct their own identity, which is different from that of adults. In terms of learning, the main orientation in adulthood is broadly towards the management of the life course and its challenges, typically centring on family and work, and more broadly on interests, life-
style and attitudes. The beginning of the adult period may typically be marked by external events, such as starting a family or finishing education. There are no decisively new cognitive opportunities; what happens in terms of learning and consciousness is that the person takes on the management of, and responsibility for, his or her own life, with this normally occurring gradually as a long process throughout the years of youth and into adulthood.

2. LEARNING SCIENCE – some background issues

There has long existed in the social sciences a controversy concerning two opposite methodological approaches to the study of social phenomena. One emphasises the methodological unity of the natural and social sciences; the other stresses the subjective quality of social phenomena, and argues that the social sciences require different methods of inquiry from those used in natural science investigations. These two methods are competitors; thus, as Hempel and Oppenheim (1953, p 330) write, "the existence of empathy on the part of the scientist is neither a necessary nor a sufficient condition for explanation, or the scientific understanding, of any human action".

Only during the last fifty years - after the emergence of science as an organised profession, have sociologists begun to pay attention to science and scientists as social phenomena. During the inexorable growth of science from the seventeenth century onwards, there was virtually no attempt to describe and analyse the workings of the scientific community. While this may be partly a reflection on the growth of the social sciences themselves, it is also partly due to the intimidating jargon and complexity of science – something that ought to have implications for teaching the natural sciences. Meanwhile, natural science has not only been solving technical problems, for example, how much vitamins to add to our cereal, it has also developed an attitude to the world which makes some things seem valuable and
others not. This cultural aspect of science is relevant when considering the
standards by which social change is judged desirable, or not. Toulmin and Goodfield
(1962) develop the view that scientists, and non-scientists alike, show increased
understanding for their behaviour when criticising each other and justifying
themselves, by citing as the factors relevant, not the physical or mechanical causes
underlying their actions but, rather, the reasons for which they acted as they did. A
consequence of Wittgenstein's contribution to the subject of meaningful behaviour is
that the social sciences were seen to be as rule bound as the natural sciences
(Winch 1958, p 63).

Just as there are two approaches to the study of social phenomena, so there are two
conceptions of science, described by Medawar (1969, p15) as the romantic and
poetical, and the rational and analytical. The former is based on the idea of
imaginative insight - "truth takes shape in the mind of the observer: it is his
imaginative grasp of what might be true that provides the incentive for finding out
what is true" (my italics). Every advance in science is, therefore, the outcome of a
speculative venture, an excursion into the unknown. According to the opposite view,
truth resides in nature and is to be got at only through the evidence of the senses
(Dixon 1973, p 24), and the scientist's task is essentially one of discernment.

These romantic and rational schools of thought have, in part, been reconciled in
Popper's hypothetico-deductive system (Popper, 1959). The scientist is seen as a
person who alternates, sometimes rapidly, between imaginative and critical phases
of thought. During the imaginative period, she or he makes a guess at some aspect
of the world, and frames a hypothesis. By deduction and experiment she or he tries
to falsify this hypothesis, and only when it has survived severe scrutiny can it be even
temporarily accepted. This line of thinking is to do with how science should be done,
as opposed to the doing of science - the distinction being between the philosophy of
science and the practice of science. Students tend to be pitched into the latter without having considered what characteristics distinguish scientific inquiry from other types of investigation, and what conditions must be satisfied for a scientific explanation to be judged 'correct'.

Another consequence of the lack of explanation of the nature of science lies in a misconception as to the nature and status of facts, for example, the existence of an absolute zero of temperature is not a fact but a conceptual matter – a consequence of the way in which we give meaning to the notion of temperature and put degrees of warmth and cold into relation with the number series. There is, of course, no connection between numbers and the notions of heat and cold until we create one. Concepts of science are formulated by thought and not by experiment – the purpose of the experimental test is to reveal whether, in the real world, that application of concepts is just or not. Learners of science at pre-degree level generally have limited opportunity to design or make critical evaluation of experiments, hence they are not necessarily aware of the assumptions that underlie a particular experiment, and so cannot see the weaknesses inherent in some approaches. A simple example can be taken from the work of Galileo who, whilst he collected evidence that the earth together with the other planets, revolve around the sun, failed to provide a theoretical reason why looking through a telescope should be expected to give a true picture of the sky. The new 'instrument based' perception was accepted as more real than was the world based on faith and belief, and it became understood that to see through an instrument (telescope or microscope), was to see a more profound reality than could be observed by the eye. The legitimacy of science came to be based, in large part, on its claims to describe a world in visual terms. The absence of a logical reason went unquestioned.

A further sense in which Galileo's discovery illuminates all other investigations is the role of existing knowledge in the assimilation of new knowledge. It is because we are
all reliant on existing knowledge to make sense of new experiences that a scientist will make use of what already counts as knowledge in deciding what should come to count as new knowledge. The existing accepted knowledge is not just the personal knowledge of the individual that has come from their own experience, it is the "inherited and shared knowledge of a given scientific community" (Barnes 1985, p63).

The problem Galileo experienced was how best to describe his observations in terms of existing knowledge, and he was forced to accept that the knowledge of science is provisional and uncertain. There is a paradox which is of relevance to science education here, for learners of science are encouraged to accept knowledge as it is accepted at any given time, with no attempts to justify or validate this knowledge. This is partly because much of the knowledge learned is procedural (and science in this respect resembles a craft), and partly due to the way the information is set out in texts and passed on in lectures, so as to create conviction. Although these issues form the backdrop to this project - where the response to new information is being tracked, issues of curriculum design and content are not part of my investigation.

Crombie (1979 vol.1) makes a strong case that it was the Greeks who invented science as we know it. In ancient Babylonia, Assyria and Egypt, as well as in ancient China and India, technology had developed on a scale of astonishing effectiveness, but, so far as is known, it was unaccompanied by any scientific explanation. A good example of this ancient technology is the methods of predicting astronomical motions by the Babylonians and Assyrians in the third century BC, but they offered no natural explanations of the phenomena they could predict with considerable skill. The texts in which they set out to 'explain' the world, as distinct from predicting its happenings, contain myths in which the visible order of things is attributed to a society of gods personifying natural forces, for example, thunder.
The Greeks invented natural science by "searching for the intelligible impersonal permanence underlying the world of change" (Crombie 1979, p 25). By hitting upon the brilliant idea of a generalised use of scientific theory they proposed the idea of assuming a permanent, uniform abstract order, from which the changing world of observation could be deduced. Thus, the myths were reduced to the status of theories, and their entities tailored to the requirements of quantitative prediction. With this idea – the generalised use of theory, Greek science must be seen as the origin of all that has followed. Thus, order was brought about by abstract thought, and it remained characteristic of Greek scientific thought to be interested primarily in knowledge and understanding and, only very secondarily, in practical usefulness. Therefore their curiosity was directed, not to the nature of the fire which baked bricks, but to the nature of fire itself. While the Babylonians made no attempt to generalise the results of their investigations, Greek thought differed from all that had gone before, in respect both of generality and of rigour. It is through general thinking that it is possible to pass from percepts - things to which one can point (such as triangular fields), to concepts - which are creations of the process of abstraction. One of the characteristics of science as understood today is the "generalisation of perceptual experience by means of adequate concepts" (Wightman 1966, p 5); whilst history records their growth, philosophy critiques their adequacy.

A consequence of the marriage of the empiricism of technology with the rationalism of philosophy, was the birth of the new empirical science - which sought to discover the structure of nature. By the beginning of the seventeenth century, systematic use of new methods of experiment, and mathematical abstraction, produced such striking results that the name 'scientific revolution' has been given to the movement. The instinctive question for a scientist to ask is not "is it reasonable?", as if it is known beforehand the shape that rationality has to take, but rather "what makes you think that might be the case?" This is a question at once open and demanding. It does not
try to specify beforehand the form that an acceptable answer has to take, but if a scientist is to persuade anyone that some possibility -- whether expected or not -- is true, then evidence in support of the claim will have to be produced. Science trades in the search for explanations that are supported by evidence that is verifiable.

One of the distinctive features of scientific theories is that they contain expressions such as 'electron', and 'magnetic field', terms which do not occur in everyday discourse, and items that these terms designate are likely to be unfamiliar to non-scientists. This has (at least) two consequences: the first is more philosophical, and focuses on the distinction between the two kinds of objects mentioned, which can be labelled simply as 'observable' and 'unobservable'. The contrast between observable and unobservable objects highlights the difference between those objects of which we can have some direct perceptual experience, and those which we can perceive only indirectly. The concern relates to unobservable entities, and the questions as to whether they exist, and of how we could come to know anything about them. Although no current curriculum approaches science by highlighting the distinction, I have been surprised at how many times it has been the source of confusion in students; this is a good example of how some appreciation of philosophy is of real value in classroom teaching. The second consequence of science having its own distinctive language is that it can be, and often is, the source of confusion and misconceptions in adults, though probably not so much in children - who are less likely to have encountered the terms before. Examples I have encountered frequently include confusion between the terms 'mass and weight', 'gene and genome', 'atom and molecule'. Casual use of language is often the cause of confusion in adults trying to express their views and, although this could be said to be associated with communicating science rather than learning it, I argue that there is a link between successful communication and understanding. An example here might be the use of skin colour as a surrogate for race, in a debate which may be trying to
link race with intelligence. Since there is no basis in the human genetic code for the notion that skin colour will be predictive of intelligence; the term has been used inaccurately, and out of context - it being a social and not a scientific term.

Habermas (1972), however, prefers not to consider the influence of the cultural (social) upon the individual, and believes that unhelpful perceptions are self-induced rather than socially induced constructs. Habermas is concerned that reason has become an instrument for the pursuit of pre-established goals and has, thus, lost its critical thrust - judgement and deliberation have been replaced by calculation and technique, and reflective thought has been supplanted by a rigid conformity to methodical rules.

According to Carr (1995), Habermas claims that the mutilation inflicted on the Enlightenment concept of reason is an inevitable consequence of the successes and accomplishments of the natural sciences. This success has, he claims, fuelled the belief that the scientific patterns of reasoning which have enabled us to extend our control over the world of nature can be used, with equal success, to extend our control over the social world as well. As a result, scientific rationality now operates as an uncritically accepted way of thinking that not only pervades modern intellectual disciplines, but also penetrates all aspects of everyday social life. Indeed, Habermas argues that the spread of scientific rationality has been so powerful, that our understanding of the relationship between philosophy and science has become seriously distorted. Instead of accepting that science has to justify its knowledge claims against epistemological standards derived from philosophy, it is now assumed that epistemology has to be judged against standards laid down by science.

Habermas (1972) calls this reduction of epistemology to the philosophy of science 'scientism', and he identifies it as 'the most influential philosophy of our time'. A consequence is that we can no longer understand science as one form of possible
knowledge but, rather, must identify knowledge with science. Habermas mounts a critique designed to undermine the dominant scientistic epistemology, by demonstrating that there are various legitimate forms of scientific inquiry, each with its own internal epistemological standards, and each oriented towards the satisfaction of different human interests and needs; these are, firstly, technical interest; secondly, practical interest, and thirdly, emancipation - deriving from a desire to be free of those constraints on human reason (ignorance, authority etc.) which impede the freedom of individuals to determine their purposes and actions on the basis of their own rational reflections. This 'emancipatory' interest, thus, gives rise to the idea of a 'critical social science' - a science that aims to enlighten individuals about the origins of their existing purposes, beliefs and actions by promoting emancipatory knowledge; this is a form of reflective acquired self-knowledge. Habermas has, thus, tried to provide a logical basis for reflective learning, although in doing so he claims that self-reflection, knowledge and interest are identical, yet he does not explain how they can be.

Adults who have enrolled for courses in Further and Higher Education that include science components are generally aware of practical reasons, beyond intrinsic intellectual interest, why they should have a basic knowledge of science. The practical reasons include a reduced likelihood of falling victim to fraud and superstition (from astrology to quack cures), and a need to understand what is really at stake in contemporary political issues (from global warming to embryo research). One of the difficulties encountered is a comprehension of the word 'science'. Quite apart from the world of advertising, where the naming of some claim or line of reasoning as 'scientific' is done in a way that is intended to imply some kind of merit or special kind of reliability, the word can refer to particular methods of discovery, or it can refer to the body of knowledge arising from what has been discovered, or it can relate to the new things that can be done with the new knowledge (technology).
Where the methods of science are concerned, some often quoted sayings that contain words that are no longer used in their earlier context can be the origin of much confusion. An example of this is 'the exception proves the rule', whereas it is a principle of science that if there is an exception to any rule, then that rule is wrong. The word 'prove' used in this way really means 'test', in the same way that one hundred proof alcohol is a test of the alcohol; so the phrase should be restated for today as 'the exception tests the rule'. All of these examples are factors that relate to knowing science and, if not taken note of by teachers, can lead to misconceptions and confusion. There is no consensus on how to achieve, (a) the encouragement of practical skills, (b) the introduction of an element of discovery into the study of science, and (c) the realisation of the importance of the sociological and economic implications of advances in science; neither is there an appreciation of the students' difficulties in absorbing the many unrelated facts. This study joins a long tradition in attempts to move towards these goals.

Munn et al (1992) collected student views through semi-structured interviews of mature students on science, mathematics and engineering courses. They found that these students stressed that, having a foundation of knowledge of specific subject areas was immensely helpful, mathematics tending to be mentioned most often. The students were, of course, speaking from personal experiences, Had they, for example, been taught thinking skills from a young age, or had their learning on the course undertaken been differently managed, then a different story might (or might not) have emerged. An apparently typical comment was: "dealing with electricity ... it's not like banking or accounting where you see what's going on. You're dealing with something you can't see - the fundamentals. Once you've picked them up, that's half the battle... previous knowledge is invaluable" (Munn et al 1992, p12).

Yet Duit and Kesidou (1988, p 193) found that the second Law of Thermodynamics does not seem to run against student's everyday experiences; "most students have
intuitively the correct idea that temperature differences tend to equalise and that the processes will not run back after equalisation." However, Barker (2000 a) suggests that the first Law of Thermodynamics is more problematic, because the energy transfers included in a system are frequently invisible. Stavy (1990) reports that children reason differently when the substance studied remains visible. This is interesting when set in the context of the trend to greater emphasis of study being laid on the invisible; fifty years ago, as a child I learned something of biology by studying whole animals. Within twenty five years biology had become interested in the cell, and now cellular biology has been supplanted by molecular biology. Is it possible that the science that is the focus of interest today has, by its very nature, become a more difficult subject for study by young minds? Critical thinking theorists (Perkins et al 1993) have noticed that there exist two essential problems that students face when they encounter the kinds of problems that fall within the territory of science. Firstly, they must possess the competence to reason critically - a competence that, at least in certain forms, has been observed to become increasingly evident with age. Secondly, they must be able to dislodge their existing beliefs from evidence presented in the problems.

The ability to dislodge existing beliefs is a difficulty that seems to transcend age groups – probably because they are enforced ideologically in the culture, although Klaczynski and Narasimham (1998) suggest that with increasing age, this difficulty may decline. Could this difficulty, to conceptualise the invisible, explain the observation by Ross (1993), that students acquire the incorrect idea that energy is 'used up'? Maybe, from everyday experience of batteries going flat, petrol tanks needing refilling, and electricity, seemingly, 'used up' in providing heat and light; or is it that the concept of energy transfer is more complex? More work on this subject needs to be done, to enable educators to understand the difficulties for 'adults learning science' that are intrinsic to the nature of the subject being studied.
While this thesis is not about the nature of scientific knowledge, and its standing as an account of physical reality, it is nevertheless considered important (for the reason given below) to emphasise the theoretical nature of science. The existing knowledge of science comprises not a direct reflection of the real world, but a theoretical interpretation of that world. Theories are invented by people, and used to describe and interpret their observations and experimental findings in terms of what is known. One consequence of this is that any finite set of observations and findings is compatible with any number of theories, so no set of observations and results can ever suffice conclusively to establish a theory (because the data produced is always finite).

Scientific knowledge is theories which we (or our predecessors) have invented, and which we are content to use for the time being as the basis of our understanding of nature, because we have found it trustworthy in use. There is no expectation that it will be permanently valid, for knowledge accepted today is not thought of as a set of fixed truths, more a developing interpretation of some parts of the world. Yet, for all this, natural scientists do have immense confidence in the accepted knowledge of their field. Professional training makes no serious attempts to justify and validate the knowledge it conveys, the presumption being that the knowledge will be absorbed and accepted. Part of the reason why it is accepted is that much of the knowledge acquired by learners is procedural, in the same way as a musician in training learns skills for a future occupation. Texts, therefore, tend to downplay problems and uncertainties, as they are designed to create conviction.

The focus on procedural knowledge existed because of the policy in schools and colleges to discover and train the few who showed some aptitude for science, as opposed to concentrating on broad schemes for the general diffusion of scientific knowledge. However, a proposal that arose from the 1957 Policy Statement of the
Science Masters' Association (called *Science and Education* and published in the November 1957 issue of The School Science Review as Recommendation No. 2) intended to change this. Rather, teaching would be 'about science', so that by the end of formal instruction, learners would have acquired some appreciation of the 'scientific attitude'. They would be able to comprehend the social and technological consequences of it, as well as knowing something of its methods. What eventually emerged from this proposal was the Nuffield Science Teaching Project. The emphasis would be on learning rather than being taught, on understanding rather than amassing information, and on finding out rather than being told.

Half a century later, in 2006, a new attempt was made in response to a perceived crisis in science education – this most delicate and vulnerable section of the scientific enterprise that is responsible for the training of future generations of scientists in schools and colleges. A new General Certificate of Secondary Education course was designed with the intention of persuading more students to take science at A-level and university by making it more interesting and relevant. The three disciplines of chemistry, physics and biology were conflated as 'scientific literacy'; children were encouraged to discuss topical issues such as global warming and MMR vaccines with particular reference to media coverage. Critics, for example Whelan (2009), argued that this approach treats science as a branch of media studies rather than as a group of discrete bodies of knowledge to be transmitted to the student, that it assumed learners can relate only to what they know and they should not be challenged by new concepts, that it replaced the controlled laboratory experiment – the backbone of modern scientific enquiry – with field studies. The danger is that pupils will be less likely to read for science degrees at university because they will just not know enough to do so. The novelist, and one-time research chemist, C. P. Snow who delivered the 1959 Rede lecture on “The Two Cultures and the Scientific Revolution” in which he warned of an academic emergency arising from a gulf of
mutual incomprehension between scientists and literary intellectuals, would be appalled at this project.

The foregoing section of this chapter is not intended to be a clear statement of current views on the nature of science; indeed it is difficult to see how characterisation of a single category "science" can be established or defended. Different areas of knowledge can be investigated concerning their aims and the means by which those aims are accomplished, and even the degree of success achieved – but there is probably no justifiable, timeless and universal conception of science or even of scientific method that can rule out certain areas of study. But these are philosophical issues and my aim in the latter part of this chapter was to highlight some background issues relating to those areas of study which, perhaps for convenience, have been grouped under the banner of science for teaching purposes at introductory level.

3. SUMMARY

This chapter has focused on two of the foundation pillars of this thesis; namely, issues surrounding learning by adults and the learning of that which is called science. There is an extensive literature relating to both topics. The survey given has, necessarily, been brief, but the scene is now set for consideration of the research problem that is the basis of this study. Chapter 5 will explore the research question, and the methods of inquiry used.
CHAPTER 5

THE RESEARCH PROBLEM
&
METHODS OF INQUIRY

1. INTRODUCTION

Chapter 2 included a consideration of the epistemological and ontological perspectives that underpin the design of this research project. This Chapter begins by developing these points that lead to the identity of the research problem. The methods of inquiry are then set out with appropriate noting of related contextual and quality issues. An explanation of the approach to data analysis used in this study completes this section of the thesis.

2. IDENTIFYING THE RESEARCH PROBLEM

The middle years of the twentieth century were dominated by 'behavioural' models of learning based, largely, on animal studies. One of the pioneers who helped to move the study of psychology from these behavioural models to cognitive models - that focus on how people construct new meanings and use knowledge in creative problem solving - was David Ausubel. His assimilation theory of meaningful learning (1962), where new information becomes related to an existing relevant aspect of an individual's knowledge structure - is still seen as comprehensive and powerful. It lies at the core of Novak's (1998) influential theory of education - meaningful learning underlies the constructive integration of thinking, feeling and acting, leading to empowerment for commitment and responsibility. Meaningful learning is contrasted with, and seen as more valuable than, rote learning, which occurs when the learner
memorises new information without relating it to prior knowledge.

Rote learning is dismissed by Novak as being of use only in the memorizing of such information as telephone numbers, but there is evidence to show that people whose lives depend on the ability to memorise large amounts of information are better at retaining information than those whose lives do not (Flood 2005). Increasingly, over the last three decades, science has been taught on the assumption that access to information is just as valid as data having to be held in long-term memory; but I think this argument has limitations, since we do not know what we do not know. The use of stored knowledge may allow us to solve a problem, since it can direct us to what we need to know. If our knowledge state is a tabula rasa, we have no starting point. My classroom observations suggest to me that there are always students showing talent in science (up to level 3) by dint of having good memories; for example, in qualitative chemical analysis, recognition of having ‘seen this before’ can save both labour and time. So my suspicion is that rote learning may play a more important role in learning science than, for example, merely recalling arbitrarily chosen distinguishing features in classification keys used within biology to aid the identification of a plant or animal, or symbols for elements.

But whether constructive integration or memorizing, learning is described in terms of a process by these education researchers in the United States. Herein appears to lie a theoretical weakness, because the implication of this kind of definition is that if the process is observed as occurring, then that kind of learning must be taking place — it is a tautology, for the proposition about learning is true by virtue of the meaning of its terms. Such definitions do not illuminate the object of their attention and, though the presence of such a weakness does not demolish the entire edifice of the cognitive approach, nevertheless, the base of the Ausubel and Novak argument is weakened in the light of this criticism. My work takes the useful learning tool devised by Novak (the concept map), and applies it to another perspective on learning.
Using the framework of the research approach called phenomenography, which aims to reveal the qualitatively different ways in which people experience, and conceptualise various phenomena in the world around them, Saljo (1979), in an interview study, investigated the notion of learning. The results, replicated by Martin and Ramsden (1987), and taken further by Marton (1988), revealed two principal types of learning which are characterized by the presence or absence of meaning, and designated ‘deep’ and ‘surface’ learning. Sub-classes of each type are described (developed further in Chapter 3), and inter-relationships are explored. Though the terminology is different from Ausubel and Novak’s, there is much common ground between deep and surface learning, and meaningful and rote learning. But there is also a weakness in this way of looking at learning - the type, or conception, of learning can only be found by asking the learner. The first question asked of all those interviewed in the study conducted by Saljo and by those who replicated the work was, “What exactly do you mean by learning?” There is no other instrument to track the response of the learner to new information, no other way of verifying that the type of learning, said by the interviewee to have taken place, is in fact the type that has occurred. Whilst it may be argued that some measure of reliability will be conferred by involving large numbers of respondents, this does not remove the presence of the weakness.

One of the aims of my study is to test whether there is a link between the conception of learning as seen by the learner, and the kind of learning that actually takes place as indicated by changes to concept maps which show what process has taken place. Thus, these two ways of looking at learning, each with their own inherent weakness, can be tested against the concept map to see if the claims made for them are demonstrable.

Adults will have spent much of their lives learning from experience, and this
experience will be both the foundation of, and stimulus for, the more formal learning which takes place in the classroom. Yet, though experience may be the foundation of learning, it does not necessarily lead to it and there needs to be an active engagement with it. Knowledge making is, thus, a participatory process in which social interaction precedes meaning making, and action - knowledge and meaning are created between, rather than within, people (Mead, 1934). Learning is, thus, intricately bound up with the formation of self, “it implies becoming a different person” (Lave & Wenger 1991 p 53). This brings us back to the idea of types of learning. The classification of conceptions of learning adopted for this study is the one developed by Saljo (1979) from a study of data collected from Open University students' views of learning, and extended by Marton (1988). The relative merits of this approach, and the differences from other systems of categorization, are examined in greater detail in Chapter 3; but it is worth indicating here that the research findings of Bloomer and Hodgkinson’s (1997a and b) Further Education Development Association (FEDA) supported longitudinal study, “do not indicate types of learner in any permanent sense” (Bloomer 2000 p. 4). While they found it was often possible to discern deeply held dispositions to knowledge and learning, how learners acted, frequently varied from situation to situation.

For the purpose of examining the response to new information that occurs in adults learning science, it is assumed that there are basically two types of learning: meaningful and rote (Novak 1998) - though other terminologies, such as deep and superficial, are in use. Meaningful learning is viewed as crucial in successful education by Novak (1998), yet adults learning science may not see themselves as meaningful learners. It may be that learners of science, at an elementary level, utilize rote (surface) learning because of methods of testing, or because it involves less effort, or even because they are encouraged to by teachers, or because, to all intents and purposes, it is effective for the task in hand. This study will ascertain
what kind of learner an individual considers him or herself to be, when dealing with
new information; it may be that the Novak view (that is so dismissive of rote learning)
should be reviewed, as it might have a more useful role than it has hitherto been
 accorded. Those learners who are not meaningful learners could, perhaps, be
helped to broaden their repertoire of learning, by changing their conception of
learning. A central aim of this research then, is to establish a means of recognizing
whether a learner has responded to new information by learning meaningfully, or by
rote. Reference has been made to a more biological view of learning. Schaverien
and Cosgrove (1999) argue that, if profoundly biological, education could then be
well explained in terms of more fundamental biological principles. Essentially, theirs
is a selectionist account – a development of Campbell’s (1960) theory of selective
retention in creative thinking, and Popper’s (1968) argument that science progresses
by means of the survival of those theories that are the fittest. Their evolutionary
epistemology posits that brain learning is a process of adaptation that can be
explained in terms of selection: “first, variants are generated, next they are tested
and then those selected by the test are propagated” (Schaverien and Cosgrove
1999:1229). By taking an epigenetic view of brain development (i.e. not reducible to
genetics alone), adaptations resulting from chance variations can be considered
developmental – which learning certainly is. The question as to whether selective
retention applies to both rote and meaningful learning, or to only one of these, might
be worth investigating in a further study.

This section has focused on the two types of learning (rote and meaningful) that are
recognized by many of those interested in the nature of learning. How learning is
achieved is still largely a matter of conjecture, as the review of some of the literature
charting attempts to establish an alliance between reason (teaching us how things
must be) and empirical inquiry (teaching us how they really are), in Chapters 2 and 3
indicate.
The research questions addressed in this study are:

1. Core question

   How do adults learning science respond to new information, especially information which conflicts with their existing knowledge?

2. Subsidiary questions

   a) Is there a link between a conception of learning (as viewed by the learner), and the type of learning that actually takes place?

   b) Can learners be helped to become meaningful learners by changing their conception of learning?

The remainder of this chapter is devoted to consideration of the methods by which these research questions are addressed.

3. TOOLS

   a) Concept Maps

   The core question in this study is to do with how adults learning science respond to new information - especially if it conflicts with their existing view, and how cognitive change is going to be tracked (mainly) by the use of concept maps. Concept maps were developed by Novak's research group in the 1970's, working from Ausubel's theory of meaningful learning, "to meet a need for an evaluation tool that can show easily and precisely changes in students' conceptual understanding" (Novak 1998: 192). They consist of a hierarchical representation of concepts and propositions that a learner has, as he or she relates to events or objects discussed, or taught. They differ from flow charts which show sequences of events rather than superordinate – subordinate relationships between concepts (Novak and Gowin 1984).
Although interviews are seen as the 'gold standard' for evaluation of cognitive structures, Edwards and Fraser (1983) showed that concept maps constructed by students were as revealing of their knowledge structures, as clinical interviews of students. Novak says that his research group was led to devise this tool due to the problem of the interpretation of knowledge expressed in interviews (Novak 1998:194). It is for this reason, and because concept maps are a useful learning tool, that they are being used in this study. Novak's claim (1998 p 194), that concept maps encourage meaningful learning and discourage rote learning, arises from his observation that long chains in a concept map are indicators of rote learning. Kinchin (2000a) concluded that linear structures are resistant to change, and that change to linear structures constitute meaningful learning. He further found that simple additions to a concept map do not, of themselves, constitute meaningful learning – although, of course, meaningful learning could still have taken place.

In relation to this study, the options for a learner, when presented with new information which may conflict with their existing world view, are:

1. Rejection – of what is new and persistent reliance on existing understanding. Evidence that this occurs in children learning science at primary and secondary levels is given in Chapter 3 of this thesis. A concept map, which is essentially unchanged after presentation of new information, may indicate rejection of the new information. An interview will be used to corroborate this conclusion because other reasons could exist; for example, the learner had simply not seen the significance of the new information, and so had ignored it.

2. Bolt-on – existing understanding is retained and used preferentially. New information is placed in a parallel compartment and applied, but only after there is a failure to apply existing understanding successfully. This is additive or rote learning that can lead to a misconception, because there are competing
frameworks held by the learner. If contextual switching (moving from one framework to another in response to a contextual cue, compared with conceptual change where the structure of a framework is altered) is developed here, this may be a functional framework, although meaningful learning of the new information has not occurred. A concept map drawn after presentation of the new information would show the additional information added in parallel to existing information, but probably no cross linking to, or from, it. This may be a transition phase, and a learner passes on to meaningful learning after acknowledging the inefficiency of the competing frameworks position.

3. Replacement of existing understanding, by new understanding which is built into a restructured concept map. Meaningful learning can be said to have occurred, and the learner has 'moved on' from the previous state. In some cases, the learner may discover the set of situations in which the old understanding still applies, and may use this as a short cut; for example, in mathematics.

Thus, once a learner has been shown how to construct a concept map, if they draw a map before and after being presented with new (and possibly conflicting) information, it should be possible to compare the maps and establish the kind of learning that has taken place. This can then be compared with the conception of learning held by the learner, as discovered by interview before and after the presentation of the new information. Strategies to help poor learners become good ones could then be worked out - noting that Suppes and Ginsberg (1963) infer that information learned by rote inhibits subsequent learning of additional similar information – even if it has been forgotten.

No tool is perfect and so some possible limitations of concept maps ought to be mentioned. Integrative reconciliation, observed as cross linkages within a concept map, is seen as a sign of meaningful learning. This corresponds with
accommodation learning in Piaget's development theory. However, if learners are aware that inserting cross links into a concept map provides an indication of meaningful learning, they will simply learn to insert these. A consequence of this will be that the indicator no longer functions as designed. This potential problem, which could be more troublesome if concept mapping was being used as a tool to promote learning rather than tracking it, can be effectively minimised by examining the map for other indicators of expertise, such as 'connectedness' and 'link quality'. Issues relating to 'assessment' of concept maps are explored in more detail later in this section. Additionally, any relationship that might exist between learning styles such as visual, and the ability to work with concept maps, has yet to be established.

The hierarchical representation of concepts and propositions a learner has, are suitably illustrated in a concept map:
Fig. 6 A concept map showing key ideas and principles exhibited in a good concept map – after Novak 1998 p 32

A concept map showing key ideas and principles exhibited in a good concept map after Novak 1998:32
Generally, these maps have been used to support and enhance learning, but in this study they are being used as a tool to track the kind of learning that has taken place after teaching. This requires that concept maps can be described and compared, and both quantitative and qualitative options are available. Although this is a qualitative study, these options need to be considered with respect to the analysis of the concept maps.

For quantifying concept map characteristics, a scoring protocol devised by Novak and Gowin (1984) is available:

Fig. 7 Scoring model for concept maps (redrawn from Novak and Gowin 1984)
Note: Relationships = 1 point per link 14 points for above model

Hierarchy = 4 layers @ 5 points per layer 20 points
Cross links = 10 points per cross link 20 points
Examples = 1 point per link 4 points
58 points total

Note: the points are arbitrary and without units. A greater number of points equate with more meaningful learning.

The procedure is not without its critics, however, Caine and Caine (1994:166) make the point that it is impossible to communicate the scope and depth of a student's abilities by means of a letter, or numerical grade. White and Gunstone (1989:38) express concern at the threat to students' potential to learn, that could result from a changed attitude (to concept maps) following the award of a grade or mark for them; and Kinchin (2001:1259) is unhappy that only 'valid' links are considered, arguing that this is unsupportive of the learning process. He claims that invalid links could have value to the student. Kinchin also refers to problems of consistency in scoring schemes, as demonstrated by Liu and Hinchey (1996).

The alternative qualitative approach, which avoids the problems associated with scoring maps, has also to steer clear of assessing a map for 'correctness' – as this would be more in line with the objectivist philosophy of 'transmission teaching' than with the constructivist approach. The scheme devised and used by Kinchin (Kinchin et al 2000), divides concept maps, based on their gross structure, into three broad categories - spokes, chains and nets. These categories are illustrated in Fig. 8, with a table of characteristics of each given below:
Table 3. Characteristics of spoke, chain and net style concept maps (after Kinchin et al. 2000)

<table>
<thead>
<tr>
<th></th>
<th>SPOKE</th>
<th>CHAIN</th>
<th>NET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hierarchy</td>
<td>One level only</td>
<td>Many levels, but often unjustifiable</td>
<td>Several justifiable levels</td>
</tr>
<tr>
<td>Processes</td>
<td>Simple association with no understanding of processes or interactions</td>
<td>Shown as a temporal sequence with no complex interactions or feedback</td>
<td>Described as complex interactions at different conceptual levels</td>
</tr>
<tr>
<td>Complexity</td>
<td>So little integration that concepts can be added without consequences for 'map integrity'</td>
<td>Map integrity cannot cope with additions, particularly near the beginning of the sequence</td>
<td>Map integrity is high. Adding one or more concept often has minor consequences as 'other routes' are available</td>
</tr>
<tr>
<td>Conceptual</td>
<td>Shows little or no 'world view'. Addition or loss of a link has little effect on the overview</td>
<td>Integrated into a narrow world view, suggesting an isolated conceptual understanding. Loss of a link can lose meaning of the whole chain</td>
<td>Can support reorganisation to emphasise different components to appreciate a larger world view or to compensate for a missing link</td>
</tr>
<tr>
<td>development</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Represents</td>
<td>National Curriculum structure</td>
<td>Lesson sequence</td>
<td>Meaningful learning</td>
</tr>
</tbody>
</table>

116
Fig. 8 Categories of Concept Maps – redrawn after Kinchin et al 2000
Of rather more use as indicators of the type of learning that is taking place, is a consideration of link quality. A table identifying some of those indicators of expertise is given below:

Table 4. Indicators of expertise in concept maps (from Kinchin 2000a)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Expert</th>
<th>Novice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connectedness</td>
<td>Highly integrated structure with numerous cross-links</td>
<td>Disjointed structure dominated by linear arrangements in isolated clusters</td>
</tr>
<tr>
<td>Link quality</td>
<td>Appropriate linking phrases which add to the meaning of concept, using the specialist language of the domain.</td>
<td>Links are often inappropriate – usually single words that add little to the meaning and using non-specialist terminology</td>
</tr>
<tr>
<td>Link variety</td>
<td>A diversity of linking phrases illustrating a range of thought processes</td>
<td>The same linking words are used for a number of links, suggestive of a narrow range of thought processes</td>
</tr>
<tr>
<td>Dynamism</td>
<td>Changes over time, reflecting active interaction with alternative knowledge structures</td>
<td>Stable over time suggesting a lack of active engagement in knowledge restructuring</td>
</tr>
<tr>
<td>Concepts</td>
<td>Concentration on overarching concepts to create an overview</td>
<td>Concentration on specific concepts indicating a limited perspective</td>
</tr>
</tbody>
</table>

It is my understanding that the terms expert and novice here refer to the subject matter, and not to expertise in drawing concept maps. Kinchin says (Kinchin 2000a: Ch. 5 p. 43), that the "structures of the framework held by a student will have implications for the mechanism of further meaningful learning". So, if a learner uses a spoke structure, then the addition of any new knowledge will not disrupt the existing framework, it can simply be added in, with a link to the core concept, but without links to associated concepts. Kinchin goes on to say that the knowledge can be assimilated quickly, but this claim does not appear to have been tested, and may be simply a theory laden observation, as is his (Kinchin 2000a: Ch. 5 p. 44) comment that, "the addition of new knowledge will be easy" for a pupil with a chain structure if there is an obvious break in, or premature end to, the sequence. His claim that the
addition of a concept near the beginning of the sequence may be so disruptive to the knowledge structure lower down, that incorporation of the new knowledge is rejected, is interesting, but also untested. Kinchin (2000a: Ch. 5 p. 44) further draws attention to a possible explanation for the different styles of concept map appearing in students work by suggesting that the National Curriculum is designed and constructed in a spoke like arrangement, whereas many teachers prepare lesson plans for delivery of this Curriculum based on chain like arrangements. These possible explanations raise questions about the reliability of using different styles of concept maps as indicators of the type of learning, and leave link quality as the most secure basis for making judgements about learning type. However, it is not easy to find examples of linking phrases which ‘add to the meaning of the concept’ and ‘use the specialist language of the domain’ (Kinchin 2000, see Table 4 above), and Novak’s text (Novak 1998) is uninformative in this area, due to a lack of examples. In this study, when instructing participants in the writing of concept maps, I tried to emphasise the importance of both link quality and variety, and, also, the language used to describe the concepts. One example used to support this was from Novak (1998 : 60):
Note: 1. Obliterative subsumption: a subsuming concept (Ausubel 1968) has a role of facilitating movement of relevant information through perceptual barriers, and provides a base for linkage between newly perceived information and previously acquired knowledge (Novak 1998:59). Subsuming concepts may become established in the course of meaningful learning, or may become obliterated in that process. This is discussed further in the section of Chapter 3 relating to learning as conceptual change.

Note: 2. Forgetting: this has both an everyday meaning - i.e. a failure to recall something, and a specific technical meaning - i.e. the kind of failure to recall after rote learning (Novak 1998:60). This is discussed further in the section of Chapter 3 relating to learning as conceptual change.

The concepts in this diagram are described in the specialist language of the domain.

There is cross linking to indicate an integrated structure, and some variety in link quality, although some novice terms are included as well, for example 'can be' and 'follows'. Repetition, while extensive, is used in some places to highlight contrast, for example, 'provides enhancement of' and 'no enhancement of'.

There seems to be agreement between Kinchin (2001) and Novak (1998) that
concept maps which are dominated by linear structures with few integrating cross links indicate limited understanding of the topic(s) depicted. Conversely, more extensive integration and more cross linking are indicators of meaningful learning. This study is trying to identify the type of learning and to compare and, or, contrast it with the type of learning as stated by the respondents in the Questionnaire.

b) Questionnaire

The questionnaire and the interview have come to be the dominant methods of collecting information in the social sciences. However, the asking of questions does not just produce answers but also reconstructs the meaning of the situation in which both questioner and respondent are involved. Questions, therefore, create a situation, and answers are only meaningful in the context of the interaction. Whenever questions are to be asked, and a choice made from a limited list of answers, it is a safeguard if they are tried out in advance, because the trial would, therefore, check that the questions are feasible for the sample. Some questions may be found useless because the range of answers will be limitless, others may force similar choices on everyone, and yet others may be beyond the understanding of some of the respondents. Without any pilot stage, the actual research is at risk of “addressing unsuitable questions to bewildered people” (Shipman 1972 p. 79). A further problem is the difficulty in avoiding the asking of leading questions which may add to the unreliability of the research; also, leading questions can lead people to choose what they consider to be ‘right’ answers, rather than what they know, or believe, to be the ‘correct’ answers. For this study I have tried to ask questions which will result in my being able to know with what conceptions the learners identify. A pilot study was conducted with the aim of avoiding the pitfalls mentioned above.

All participants were asked to complete the ‘Descriptions of Learning’ questionnaire given in Appendix 1. The six categories of learning are identical to those given in Marton and Saljo (1984), whose work was corroborated by Giorgi (1986). One
advantage I have found in using Marton and Saljo's terminology is that it does not include the terms 'deep' or 'surface' learning, nor 'meaningful' or 'rote' learning. This removes a temptation that might have led some participants to select a conception of learning which they thought they 'ought' to be using, in preference to the one which they were, in practice, really using.

The questionnaire fits into the field work schedule as indicated in Appendix 4.

c) Interview

In interviews, the interaction between questioner and respondent is not only structured by the questions, but also by the personal feelings of both involved. The choice between using questionnaires and interviews is, amongst other things, a choice between reliability and insight. In interviews adjustments for any misunderstanding arising from linguistic considerations can be made, and answers can be probed. But the cost is reliability of the results because, if the same interview was carried out by a different interviewer, the chance of identical results would be low.

Interviews not only depend on the quality of the questions asked, but also on the awareness of, and control over, the interaction involved. Whilst the benefits of training have been illustrated by Durbin and Stuart (1951), the danger of interviews by only one researcher is that tone of voice, anticipatory gestures or some other action may interfere with the process, with the result that the eager researcher conducting the interview will get the answers she, or he, seeks. Therefore, it may be observed that, as Shipman found, interviewees tend to pick up clues and give the answer the interviewer wants.

Short interviews are needed, a) to confirm the conception of learning held by the learner, and b) to ascertain whether any change in that conception of learning has taken place - as a result of dealing with any new information presented in the
teaching. Examples of the questions that were asked are given in Appendix 3.

4 CONTEXT FOR THE FIELD WORK

a) College Context

Field work was carried out at a West Country college which offers courses at both Further Education and Higher Education levels. The latter is run under the auspices of a relatively local university. The Further Education students are drawn from a catchment area that, while predominantly from the county in which the college is located, also includes parts of two neighbouring counties. Higher Education students are drawn from throughout the United Kingdom, with a small proportion from other countries. The study focuses on adults learning science. Data has been produced from students pursuing courses in which the science component is subsidiary to the main part of the course, for example, HND Media Make-up - which includes a cosmetic science module - and Access to Higher Education Health Studies - which includes the study of physics, and National Certificate courses for Pharmacy Technicians. These courses were selected partly for convenience – I could be sure in advance that these courses would be well subscribed and contain learners with a rich variety of learning histories.

b) Students

The learners have in common an absence of formal training in science beyond GCSE level, and a gap of at least five years since they left full time education. The majority of these are female and aged between twenty and thirty years; selected biographical details of two of the groups of participants are given in Appendix 5. A total of twenty eight students participated in the field work, ten of these having some practical involvement with science - pharmacy technicians (although much of their work revolves around stock control, administration, and security procedures). Twelve students -make-up artists - have backgrounds in hairdressing, beauty therapy and artistic design work. They are creative artists by inclination, and scientific methods
are (initially at least) viewed by them as alien to their environment and experience. The six Access to Higher Education Health Studies students have not, for a variety of reasons, succeeded in their career ventures, and have, therefore, returned to full-time education; they have fewer academic qualifications than those in the other groups, though all aspire to Higher Education courses. Some implications of the selection of these students as participants in the study are considered in the section on 'sampling', found in Quality Issues a). It should be added that motivation is universally high with, significant personal investment in the courses.

c) Teacher as Researcher

A stereotypical view of the scientist is that of a person operating in an objective, unbiased way, accurately recording sense impressions, and consequently making factual statements about the phenomenon under investigation. A claim of the scientific community is that the truth value of factual propositions concerning the world can be established through the unbiased use of the senses. Such observation statements provide a solid empirical basis of facts from which theories are worked out, though this is controversial territory from a philosophy of science aspect. The situation is different in this investigation, because the teacher is not an unbiased observer but an agent of change, who engages the learner in constructing and owning his, or her, learning (transformative methodology). The attitudes, methods and expectations of the teacher will change over time - at least they have in my case, where a transmissive approach dominated the first half of my working life. These changes have been prompted by a mixture of imposed constraints - curricular and institutional demands, personal development, and student agendas. The relationship between student agenda and amount and type of learning is outside the scope of this study, but Anderson and Lee (1997) identify that where students hold different agendas, the chances of meaningful learning are reduced. Jarvis's book, The Practitioner – Researcher' (Jarvis, 1999), contains much that is helpful and relevant.
to the teacher as researcher, in particular the recognition given to the interrelationship between research and learning (p.164)

Black (1993 p. 81) states that, "Human subjects are often capable of identifying what the operational definition of a set of questions might be and answer accordingly". The act of becoming involved threatens the maintenance of objectivity and, as teacher, I cannot but be involved. So, though I can hope and, or, claim there has been no distortion of the situation, some doubt must be cast on the reliability of my findings. Rosenthal and Jacobson (1968) describe a striking experiment to illustrate how the teacher's expectation of the learner's performance can be established without any real evidence, yet can somehow be used to bring the performance up to that expected. If I have expectations which serve as a model for moulding students, this may produce just the results I expect, or even want. Even so, I do have a role in the assessment of my students, and it will be, as a consequence of this, that some of them try to be overly helpful and provide information that is not wholly true, or will be exaggerated, or under emphasized. At least the information is not being gathered surreptitiously, and I am not asking for co-operation without explaining the situation to those who have agreed to participate. However, I am mindful of Black's (1993: 81) caution, that "the best planned scheme for data collection may not be as good as hoped because of the fickleness of a significant number of members of the sample". Sometimes this can be avoided by sufficient insight into the characteristics of the sample, and how the instrument will be perceived, but I identified it as a potential problem area when evaluating the data.

5. QUALITY ISSUES

a) Sampling

The classical position is that the sample is only representative of the population from which it was selected, and inferences should not be made beyond that population.
However, some generalisability can be obtained on the basis argued by Bryman (1988:90), that qualitative research follows a theoretical, rather than a statistical, logic: "the issue should be couched in terms of the generalisability of cases to theoretical propositions rather than to populations or universes". The nature of this link between sampling and theory is developed by Mason (2002: 93-94): "theoretical sampling means selecting groups or categories to study on the basis of their relevance to your research questions, your theoretical position ....... and most importantly the explanation or account which you are developing. Theoretical sampling is concerned with constructing a sample ....... which is meaningful theoretically, because it builds in certain characteristics or criteria which help to develop and test your theory and explanation'. So, some sampling choices are more 'meaningful' than others.

Black (1993) rightly draws attention to the numerous reported research projects that use students in the academic institutions of the researchers, simply because those students are, conveniently, available. I, also, have followed this pattern of 'convenience' sampling, for reasons of availability and cost, but also because the results of a pilot study suggested that such a sample would provide access to enough data, and with appropriate focus, to enable me to address my research questions.

Concerning the size of the sample, Bertaux and Bertaux-Wlane (1981) claim that, the size of sample is dictated by the social process under scrutiny, i.e. the researcher samples until he, or she, knows that he, or she, has a picture of what is going on, and can generate an appropriate explanation for it. While this can be criticized for being unsystematic, it does, to some extent, counterbalance an attitude that it is a requirement that a population be represented according to certain rules. In other words, there may be situations where an illustrative approach can be more illuminating than that which emerges from representational logic.
Whilst I must allow that such things as gender, class and ethnicity, may all be relevant in exploring the learning of science by adults, I want to ascertain whether the commonalities that exist in my sample (limited and, or, poor appreciation of science based on secondary school experiences more than five years ago), transcend these other issues. The pilot study suggested that age, gender, and class, were not the determining factors but, of course, I acknowledge that these may have some relevance to the process of adults learning science.

b) Ethical

Whilst the application of constructivist beliefs may avoid some of the weaknesses of the conventional paradigm (the objectivist approach) identified by philosophers, these beliefs do, however, pose greater ethical risks than traditional scientific inquiry. These risks have been documented by Lincoln and Guba (1989 p. 132-135). The first one they identified is that of face-to-face contact – the interview, which can be subject to violation of trust, to shading the truth, to misunderstandings regarding the purposes of an interview, or relationships with other respondents.

The second risk posed by constructivist evaluation is the difficulty of maintaining privacy and confidentiality. As Skirtic, Guba and Knowlton (1985:111) noted: "such protection (privacy, confidentiality and anonymity) must be difficult to extend and impossible to guarantee. Even if all the names and places and dates are changed ‘to protect the innocent’, it is quite likely that other locals will be able to pinpoint the agencies and parties involved”.

Lincoln and Guba’s (1989 p 134) third risk concerns violation of trust. Constructivist inquiry is built on an assumption of non-manipulative trust between researchers and participants, but this can be difficult to achieve if, as is often the case, much has to be accomplished in a very short time.

The fourth possible risk to constructivist inquiry results from the need for open negotiations between researcher and participant, since deception is expressly
forbidden. In conventional scientific inquiry, deception can be permissible under certain circumstances, for example, the so-called double blind test for assessing physiological response to 'foreign' substances. While there was no need to consider deception in this study, nevertheless, the constructivist researcher needs to be conscious of his, or her, motives.

The fifth risk identified by Lincoln and Guba (1989) is one that is inherent in the framing of case studies. The inquirer has to choose what the purposes of the case are to be, and to draw on data that could illuminate those choices. The problem of how to determine what shall be included, and what excluded, can be judged only on whether the product demonstrates 'integrity, originality, passion, commitment and balance' (Lincoln and Guba 1989 p 136). Like artistic renderings, there is no simple set of rules for saying whether a given product is better than some other product.

Despite all of these problems, the case for the ontological and epistemological positions of the constructivist paradigm, militate against many of the difficulties of applying positivistic methods to social inquiry. All of those taking part were volunteers aged above eighteen years. Permission to involve these volunteers in the research for this study, was sought and obtained from the Principal of the College at which they were studying. Much of the data for this study was generated via formal teaching sessions. Students had the option of not participating in the study, but the same learning opportunities were available to all. Their completing of the 'conceptions of learning' questionnaire (Appendix 1), and my dealing with any queries arising from their participation, were carried out within contact tutorial time.

c) Validity and Reliability

Issues of validity will be considered first. Kirk and Miller (1986 p 21) summarise the issue of validity as "a question of whether the researcher sees what he/she thinks he/she sees", and they identify three types of error: seeing a relation when it is not
correct, rejecting one when it is correct, and asking the wrong questions in the first place. Flick (2002 p 222) neatly summarises Hammersley’s exploration of the researcher’s constructions by identifying three premises:

"a) the validity of knowledge cannot be assessed with certainty. Assumptions can only be judged for their plausibility and credibility,
b) phenomena also exist independently of our claims concerning them. Our assumptions about them can only more or less approximate these phenomena,
c) reality becomes accessible across the (different) perspectives on phenomena. Research aims at presenting reality not reproducing it".

Hammersley (1992 p 50-52)

Using these premises, Flick (2002 p 222) argues that the question of validity of qualitative research becomes a question of how far the researcher’s constructions are grounded in the constructions of those whom he, or she, studied. Thus the production of the data becomes one starting point for judging their validity, and the presentation of phenomena of the inferences drawn from them becomes another one. The trend here is to locate validity in the process of research and the different relationships at work in it, the move being away from a level at which concrete criteria are formulated, in terms of which a study can be assessed. Glaser and Strauss (1967 p 5) are very sceptical as to the applicability of the canons of quantitative research as criteria for judging the credibility of substantive theory based on qualitative research. This scepticism has been the stimulus for attempts to develop ‘alternative criteria’, in which qualities such as trustworthiness, credibility, and dependability, are used. Procedures from other disciplines – such as auditing from the world of finance – are utilised to strengthen the assessment of research work.

The wide range of techniques potentially available in assessing validity can appear quite daunting at the planning stage, and one needs to remember that not all of them will be used on any one piece of research. This project relies on the rather more
'traditional' process of triangulation to assess validity. Denzin (1989 p 236) claims that the "triangulation of method, investigator, theory and data remains the soundest strategy of theory construction". Although triangulation was first conceptualised purely as a strategy for validating results, its focus has shifted somewhat, to become an alternative to validation which increases the scope, depth, and consistency, in methodological proceedings (Flick 2002 p 227). It has effectively moved closer to Glaser and Strauss's strategy for theoretical sampling, where precise information illuminates emerging theory thereby extending the possibilities for producing knowledge.

In this study, methodological triangulation (Denzin 1989 p 237-241) is used to test the validity and reliability of data obtained from each participants' questionnaire, interview, and concept map. This does ignore the view that different methods and data sources are likely to throw light on to different social or ontological phenomena, and it also implies a view of the social world which says, there is one, objective and knowable social reality, and that all I have done is to work out which are the most appropriate triangulation points by which to measure it (Mason 2002 p 190). Yet this criticism can be levelled at any research design that includes multiple methods, and is a type of argument that states, 'they would say that wouldn't they'. The weakness is important, because the validity of interpretation of the results is dependent on the validity of the method used to obtain them.

Concerning interpretation, I have to be able to demonstrate that the evidence collected is both accurate and reliable, and that the interpretation I place on it can be justified in terms of the route by which it was reached. As Mason (2002: 192) says, "the basic principle is never to take it as self-evident that a particular interpretation can be made of my data", but, rather, that the steps through which the interpretations are made are continually and assiduously charted.
Concerning reliability, research in the quantitative tradition generally relies on the standardisation of research instruments, and on cross-checking the data yielded by such standardised instruments. Kirk and Miller (1986 p 42) urge the rejection of accepting as reliable the results of enquiry that are dependent on frequently repeated data collection which leads to the same results. They say, “if this form of reliability is used it may be more convenient to mistrust rather than trust the dependability of the data”. One of the reasons for this is that qualitative studies are not usually carried out on unchanging objects. Flick (2002) identifies some ways in which reliability of interpretations can be increased through training of the researchers, with the aim of improving the quality and consistency of their observation and documentation. Essentially, therefore, the criterion of reliability is rooted in the dependability of data and procedures against the background of a specific theory of the issue under study.

Concerning issues of reliability and validity with use of concept maps, Novak (1998 p 192) says,

The validity is relatively transparent because it is obvious that the fundamental characteristics of constructivist learning is exemplified in a well constructed concept map. For any competent evaluator, it is relatively easy to see if propositions indicated on the map are valid and to determine if the superordinate/subordinate nature of concepts in the structure makes sense.

Novak (1998 p192) also says that,

Over the past two decades, in dozens of studies by our research group and other researchers, concept maps have been shown to be highly reliable assessment instruments.

The term ‘validity’ is also applied to the kinds of link made in concept maps; thus a link could be valid in terms of providing a factually correct statement, but inappropriate when considered in context of the core concept under examination.
Validity here is an indicator of link quality, and the map will be examined for 'indicators of expertise', particularly 'connectedness' and 'link quality', when evaluating whether meaningful learning has occurred.

Some of the hazards of both interviews and questionnaires have been hinted at in the section on 'Tools'. The interview is a very artificial situation, and if I ask a question about a conception of learning, there is no guarantee that the answer given is either the true opinion of the respondent or, if a true opinion, whether it is correct or not. By definition, I am setting limits to what the respondent can say, and finding out what these people will say when they are being interviewed, or filling in a questionnaire. My hope is that by integrating these approaches with the concept maps, a clearer picture of how adults respond to new information in science will emerge.

d) Generalisability

Concerning generalisability, the qualitative researcher has to try to find a balance between recognition of difference and the justification of representativeness of findings and conclusions. As in any branch of science, the principal question must always be, 'what is it that we have evidence to believe is actually the case?', and to avoid, wherever possible, the unfruitful approach which asks what it might be reasonable to suppose. Mason (2002) emphasizes the importance of contextual grounding for generalisability claims - that is, the need to identify the grounds for making a claim, and not merely the claim itself. Bryman (2001 p 102) points out that it is difficult (without further work) to assess whether there is a time limit on the findings generated by a research project. I shall have to accept, therefore, that there is the possibility that my findings could be temporally specific.

In the world of the physical sciences, the word 'generalisability' is never used, instead, the word 'extrapolation' is preferred, being used to describe a process
applied to data in the search for laws which govern the physical world. Interestingly, Alasuutari (1995 p156-7) suggests that generalization is a word that should be reserved for surveys only, and that extrapolation better captures the procedure in which the researcher demonstrates that the analysis relates to things beyond the material at hand. It is not out of place to mention, though, that manuals of experiments in the physical sciences caution the experimenter to note that extrapolation is often a hazardous undertaking. But to be practical, every scientific enterprise tries to discover something that will apply to everything of a certain kind, by studying a few examples; the key to legitimate generalization is cogency of the principles on which the research is designed. The social sciences cannot provide a stock of law-like generalizations with strong predictive power; what they do discover are probabilistic generalizations, though, as Macintyre (1985) argues, the labelling of them as probabilistic does not illuminate their characteristic of being generalizations.

Concerning generalisations, qualitative research tends to be context specific but, in order to generalise the findings, the context link has to be set aside so that it can be seen whether these findings are valid, independently of the specific contexts. There is no obvious link between the sampling process and the degree of generalisability of the results; for example, if I mistake a small population for a sample, then I have no grounds on which to make inferences to a larger population. But the transferability of an emerging theory into other fields, is a wider issue in the evaluation of a research project, and Corbin and Strauss (1990 p 16) suggest four aspects on which to focus for judging both theories, and procedures, that led to them. Firstly - the validity, reliability and credibility of the data, secondly - the plausibility and the value of the theory itself, thirdly - the adequacy of the research process which has generated or tested the theory and, fourthly - the empirical grounding of the research findings. The process by which this evaluating can be done involves constantly comparing the
data, consideration of apparently anomalous and extreme examples, and the testing of findings and their context in more general and abstract situations. Put in very simple terms, generalisations require claims to be well supported.

e) Interpretation

When evidence is being interpreted, if only data which fits a particular hypothesis is selected, this will result in bias. Critics will, therefore, justifiably maintain that consequent evidence presented is not convincing, or that an alternative, or conflicting explanation is possible. Theory building by analogy, and dependence on case studies for credibility, are both forms of selective interpretation. Analogy, whilst being an important source of insight, is not evidence that can confirm the truth of that insight. Whilst I have adopted the case study style, my research is not built on the full case study approach.

The opportunities for fallacious interpretation are many. When generalisations about individuals are made from examples of collective behaviour, this can result in what are termed aggregative fallacies. There is a reverse of aggregative fallacy, namely individualistic, or atomistic fallacy, which occurs when information collected from individuals is used to generalise about societal structures. There is a greater risk of this occurring in this study.

Evidence which has been gathered but is not considered during interpretation can result in conclusions not appearing to relate to that evidence – a situation described as a disembodied interpretation. In relation to this study, therefore, there needs to be an adequate basis for any generalisations reached. Since I have no interests to declare, for example, I am not commissioned to carry out this research, and no conscious incentive to produce a slanted study, I am less likely to avoid deceptive interpretations than if this were not the case.

The temptation to extend the meaning of evidence - by treating facts as elastic, and
to generalise from inadequate, or irrelevant evidence - can remove most of its worth from a piece of work. The generalising from inadequate evidence, for example from ignoring non-response, and then making an assumption that those who did reply represent those who did not, is an illustration of extending the meaning of evidence. The related fault of generalising from too small, or too unrepresentative, a sample is one that needs to be given due consideration in the discussion of the outcomes of this study.

The demand from the general public for comment on topical issues, by those with authority and responsibility, is one frequent excuse for the use of generalisations which outstrip evidence. For example, before the relation between social class and learning performance had been thoroughly investigated in the early 1960's, there was a tendency by commentators within the sociology of education to generalise about 'the school', with, as Shipman (1972 p149) says, "very small bricks of evidence mortared with much guesswork". There is always a danger of elaborating unsubstantiated theory and resting too much weight on too little original work.

Frequently there are competing pressures to produce evidence in an unambiguous form for decision making, with regard to such things as the gap between assumptions about real situations and the reality itself. The success in demolishing established beliefs, compared with the failure to provide conclusive evidence for, or against, such innovations as the modular curriculum, could be said to be an indication of the blunt nature of social scientific instruments. They can produce evidence powerful enough to show that things are not working according to expectation, or hope, but not precise enough to compare different methods of learning. This is an example of where evidence can be produced to challenge but not to prove. The standard test for any theory is its ability to predict; however, being able to state that, 'given this combination of factors, the following can be expected', is something that can be said
rarely where people are involved.

An underlying question which is always present is, 'how much can be reasonably expected from a theoretical model?'. That all the models used are, more or less, limited is obvious from the start of any project, because, if a complete model were available there would be no need for policy documents, as the problems would already have been solved. A good (though not recent) example is the Coleman Report (Coleman 1966) which received praise as a description, and powerful indictment, of the (then) effectiveness of American schooling, but was criticised for the analysis of the results. The criticism (Cain & Watts 1970) focussed on non-response, errors in measurement, interpretation of information used in the analysis but not collected as part of the investigation, the statistical analysis, and the theoretical model used. The author’s reply to the critics (Coleman 1970) accused them of over estimating the state of knowledge about achievement in schools and, as a consequence, over-estimating the degree to which sophisticated statistical techniques were appropriate. Aiguer’s (1970) comment on Caine and Watts’ critique and the author’s defence, pointed out flaws in both and so the verdict of 'not proven' became an inevitable fate for the report. Sadly, this can happen so easily to policy-orientated research: if written for a wide audience it is vulnerable to criticism from professionals, if it employs sophisticated conceptual and analytic tools it may win the respect of the professionals but will mystify and thereby annoy the policy makers. Criticism is inevitable and yet the critiques are legitimate because both clarity and reliability are needed if far-reaching policies are to be based on the findings. The relevance of this to my study is quite specific - I need to demonstrate a level of competence as a researcher that is appropriate to a doctoral thesis but, at the same time 'the reader should be able to read the text without difficulty' (University of Surrey Research student handbook 2007-2008 p. 48).

One of the most famous projects in the history of science was Gregor Mendel's
nineteenth century experiments with pea breeding, which led to the modern principles of genetic inheritance. His work has long been overshadowed, however, by accusations that his results were statistically ‘too good to be true’ – that he must have ‘doctored’ data to fit his emerging theory of what are now labelled dominant and recessive genes.

Mendel observed (in the Augustinian monastery at Brno, today in the Czech Republic) how features of plants and their seeds changed over eight years. He published his results in 1865 but it was seventy years before the British biologist and statistician R.A Fisher suggested (Franklin 2009) that data must have been falsified – though probably by an assistant rather than by Mendel himself. The probability that real data would fit Mendel’s expected ratios between dominant and recessive traits was only seven in one hundred thousand, Fisher calculated. Present day thinking is along the lines that Mendel may have neglected observations that would have made his findings less clear-cut. Mendel’s note-books, which might have provided evidence to support or refute these suggestions, were burned after his death. The example, nevertheless, remains a classic warning of the perils of data selection (or data fudging as it is sometimes described), irrespective of how significant a discovery might be for the development of a theory or technology. Researchers and consumers of research alike need to remember that every “proof” and every “truth” of science is brought to us by human beings who are far from infallible. New technology increases the scope for alteration, for example, by digital manipulation of images. Though the efficient conduct of science, and maybe of all investigative enterprises, depends on trust between researchers, scrutiny processes must be capable of detecting, reporting and resolving research misconduct.

Experimental anomalies (referred to in the paragraph above) are often the things that expose the shortcomings of contemporary thinking yet, instead of being greeted with delight by the scientific community, the things that don’t make sense are often the
downfall of any scientists who embrace them. The history of science is strewn with examples, from the seventeenth century Danish astronomer Ole Roemer whose suggestion and demonstration that light does not travel infinitely fast, was dismissed, to Alfred Wegener who proposed the idea of plate tectonics in 1915 only to have a symposium organised to discredit his idea. Little use seems to be made of hindsight in this respect.

The relation between theory and practice differs in experience from the somewhat manicured accounts in textbooks on how to do research, and the situations presented in the field. Experience also brings to life phrases such as, 'the value laden nature of facts', and the concept that, the 'same sets of facts can support more than one theory'.

6. PRACTICAL MATTERS

a) Choosing Topics

Choosing topics suitable for the research was done after identifying criteria to use in the field work: firstly, the topic would be part of the content of the course being studied by the participant. Secondly, the majority of participants could be expected to have an elementary knowledge of the topic — ‘something to build on’. Thirdly, development of basic knowledge to the level required by the course could be covered within a one hour teaching session. Fourthly, some undisputed ‘facts’ and terminology would be included.

Although these criteria may appear restrictive, a variety of topics suitable for the purpose was drawn up. An example illustrating the difference between basic understanding and extended knowledge is given in Appendix 2.

Novak (1998 p. 227 in his Appendix 1) gives suggestions on how to make ‘good concept maps’, and claims that young children learn quickly how to construct these, whereas secondary school or university students often have difficulty, partly, he
suggests, as a result of years of habit with rote learning. This may (or may not) be the only reason; I can see that introducing concept maps as an aid to achieving meaningful learning at a stage when a learner’s study pattern has already been established, may encounter some resistance. Although the principal application of my proposed use of concept maps is to be indicative of a type of learning rather than to be a tool to promote learning, I recognized from both Novak and Kinchin (2000a) who used concept maps to promote meaningful learning, that adequate time for training in the construction of these was going to be necessary. Learners needed time to refine the (new to them) format for presenting information. Classroom experience has shown that adults are inclined to be more ‘risk averse’ than children; this technique could be viewed as ‘new’ and, therefore ‘risky’. Pre-instructional maps were drawn following presentation of material kindly supplied by the University of Surrey; these are included as Appendix 6. These maps have a pronounced and obvious hierarchical structure, and a ‘net’ structure (as opposed to a ‘wheel’ structure). Emphasis was laid on the benefits to the students, since they were investing some of their time and energy in the investigation.

b) Interviews

Interviews took place, at times convenient to the participants, in my office at the college - a room known to them, and where there is a good chance of not being disturbed. Each interview lasted a maximum of twenty minutes and, with the prior agreement of interviewees, the event was recorded. Anonymity and confidentiality were assured concerning the identity of each interviewee and their contribution.

c) Time Frame

Concerning the time-frame for the field work, a requirement of the method to be used is that it has to be quick to administer and simple to explain to the participants. But it must be rich in content if it is to yield useful insights. The time frame for each group
must necessarily be tightly structured, because the programme for the courses moves quickly through the topics it contains. An example is given in Appendix 4.

Some uncertainty has to be acknowledged, and this arises from the work of Vygotsky (1978), though his work was carried out with children. Vygotsky was trying to discover how the developmental process related to learning capabilities, and found that he needed to determine both achievement (actual developmental level) and potential (his so-called zone of proximal development). He found (Vygotsky 1978 p. 90) that in children developmental processes do not coincide with learning processes, since the former lags behind the latter. The time lag - if it exists in adults as well - may mean that conclusions reached within the proposed time frame may be applicable only to the point at which measurements are made (i.e. the second concept map), and not be either a guide to, or predictor of, eventual achievement.

An obvious follow-up here is to repeat the concept map drawing exercise after, say, one month or three months. I did try this in the pilot study and found that, because the curriculum had moved on to quite different topics, some ‘revision’, or reminder, of the original topic was needed. I could not be sure that I was not channelling their thinking in a particular direction, and considered the process to be too unreliable to repeat. It is possible that certain topics, or courses, where knowledge is regularly reinforced would provide opportunity to explore this.

d) Discussion of some practical issues concerning my empirical research:

Earlier parts of this chapter have addressed issues relating to the methods of inquiry by considering them in a broad context. Some discussion focusing specifically on the empirical work I did is now appropriate.

Firstly, concerning data production, and for the needs of this research project I was fortunately placed with regard to sources of volunteers to be participants. Though recruited and engaged as a lecturer in chemistry, I soon found my services demanded
across several departments for specialist inputs to courses which were not primarily science based but which contained mandatory modules in science. Thus it was I came to teach cosmetic science to make-up artists (HND Media Make-up), physical sciences to trainee beauty therapists (BTEC level 3 Beauty Therapy), and textile technology to art and design students (BA Design (textiles)); this being in addition to courses with a more obvious science link, such as pharmacy technician training, GCE A-level, and Access to Higher education courses.

These courses provided me with a source of participants rich in their variety of experience in learning science and their attitude to it, and in the level of teaching — though this did not emerge in the analysis because timetable constraints arising from the modular structure of the courses dictated the times for carrying out the field work and it happened to coincide with the early stages of each module being used. It was my original intention and plan to have parallel field work carried out in another, and similar, college by a former colleague who was interested in the project. However, an unplanned career move intervened and the opportunity to expand the scope of my research with a second college and a second teacher was lost. On the positive side, I was able to proceed with 28 participants from 4 different courses at 3 different levels, and this generated plenty of data.

Secondly, concerning the 'Descriptions of Learning' questionnaire, all 28 of those who had agreed to participate in this study, completed the questionnaire. A copy of the questionnaire completed by Heidi is included in Appendix 1 page 224. The reasons for including the questionnaire are, firstly to try to determine whether there is a link between the conception of learning as viewed by the learner, and the type of learning that the concept map indicates is taking place (subsidiary research question 2a, page 109, and secondly, the questionnaire is able to contribute to the reliability of the study by forming part of a triangulation strategy (see below and page 149). Answers given in the questionnaire were confirmed at interview. The contribution made by the questionnaire is best seen in the 'Discussion of Outcomes' chapter (Chapter7), for example, with Heidi,
on page 179.

Thirdly, concerning the interviews, these were always intended to be both supportive of and additional to the concept map which is the prime indicator of the type of learning taking place. The interview serves to sit alongside the concept map, either in confirmation of what is indicated, or, perhaps to provide an alternative insight, and to discover whether the learner is aware of any change in conception of learning is taking place, or has taken place. The interview also provides opportunity for a short tutorial – where necessary – to clarify understanding of the topics that have been taught. To illustrate just how the interview informs the analysis of the concept maps, a transcript of the interview with Heidi is included in Appendix 3 (page 226). When this is read in conjunction with pages 154-157 and pages 178-180, the evidence based nature of both the analysis of those aspects of the nature of learning that are being investigated in this project, and of the conclusions, become clear.

Fourthly, concerning selection from the total number of participants of those for detailed analysis and inclusion in the thesis. Two students were not present for part of the training session in concept map drawing and were unable to complete concept map, though they did complete the questionnaire; their contributions were, therefore, not available for selection. Thus, 28 learners completed the Description of Learning questionnaire, 26 completed one or more concept maps, and 28 learners participated in interviews.

The problems relating to the need to weigh width against depth when sampling from any population have been explored, albeit briefly, on page 145. Selection from the 26 eligible respondents could have been achieved in any number of ways, but some obvious examples include:

1. random, for example every $n^{th}$ name from a list created according to some schema, such as alphabetical by surname,
2. selective on the basis of age or gender, or course being studied, to give examples of each category,
3. scientific correctness of concept map,

However, as explained on page 153, I opted to select examples for inclusion which would 'illuminate particular characteristics of the respondents', for example, disposition to learning as shown by Heidi and Jonathan. Of course, all the perils of data selection loom here and I hope I have not neglected observations that would have provided a different insight into the learning process.

Finally, a word about the triangulation process. While as originally conceptualised (by Webb et al (1966)), it was associated principally with a quantitative research strategy, increasingly, triangulation refers to a process of cross-checking findings derived from any research strategy. In my study, this cross-checking opportunity between the conception of learning as viewed by the learner and as portrayed in their concept maps can give potentially useful information about the presence or absence of any link between these two. The interview affords a further opportunity to clarify or confirm the learner's views about the existence or absence of such a link. Thus, in the analysis of Heidi's concept maps which indicate quite clearly that she learns by rote, reference is made (page 179) to the evidence from the questionnaire she completed, also to the comments in the interview (page 157 and Appendix 3 line 32). This cross-checking is an important feature of any study and I believe it adds credibility to the conclusions that were reached.

7. DATA ANALYSIS

While research methods generally adopt a linear model (theory, hypothesis, operationalisation, sampling, collecting data, interpreting data, validation), the central feature of grounded theory methods is circularity of the processual parts. This circularity is, it is argued (Flick 2002), is one of the strengths of the approach, because it forces the researcher to, "permanently reflect on the whole research process" (Flick 2002 p 43). This reflection, which arises from the close link between collecting and interpreting data on the one hand, and the selection of empirical
material on the other, is not facilitated by the traditional linear method of proceeding. The circular interlinking of empirical steps, as suggested by Glaser & Strauss (1967), is considered by Flick (2002 p 45) to do justice to qualitative research.

It is neither appropriate nor necessary to include here a history of the development of grounded theory methods, it is, nevertheless, important to define and describe the method that is to legitimise this research. Glaser and Strauss’ (1967) articulation of their research strategies was a timely challenge, in social science history, to the predominance of the quantitative research paradigm in the social sciences. Qualitative methods were viewed as lacking in rigour, and assumed to be capable of producing only descriptive case studies, rather than theory development (Charmaz 1995). Glaser and Strauss (1967) not only provided a persuasive intellectual rationale for conducting qualitative research, they also gave detailed guidelines both for research strategies and for analytical procedures. Grounded theory methods comprise systematic inductive guidelines for collecting and analysing data to build theoretical frameworks that explain the collected data (Charmaz 2000 p 509). Yet grounded theory is impossible to position in relation to other methods, because the strategies it offers are flexible and not rigid prescriptions. Thus, it can come close to traditional positivism (with its assumptions of an objective, external reality and objectivist rendering of data discovered by a neutral observer), or it can lean in the direction of post-positivism, by giving voice to respondents, in what Charmaz (2000 p 509-535) terms constructivist grounded theory.

Some relevant aspects of grounded theory techniques are given below:

Concerning data.

Data means, literally, things that are given, i.e. there, waiting to be found; it assumes a positivist view of the world. But, if knowledge is created and constructed -- as is believed by the author of this thesis, then data are not given, but produced.
Therefore, a different word is needed, which stresses how knowledge is a product, and not a given. Every research method is really a means of producing, not collecting data, for none of them simply records 'the facts' or 'the truth' as an external object. What distinguishes both social and natural science from common sense, and from ideology, is method. The evidence and how it was collected and treated must be made available to others, as is being done in this chapter. It also needs to be remembered that grounded theory methods specify analytic strategies, not data collection methods. Charmaz (2000 p 514), referring to Creswell (1997), points out that these methods have become associated with limited interview studies – as if limiting grounded theory methods to interviews and limiting the number of interviews, are both acceptable practices. Researchers can, in fact, use grounded theory techniques with varied forms of data production.

Glaser's comparative approach and emphasis on process afford useful strategies for the making of data analysis to be efficient and productive, but without formulaic techniques. He (Glaser 1992) does, though, warn every qualitative researcher about forcing data into preconceived categories through the imposition of artificial questions. However, data producing often demands that questions are asked and hunches followed, though what respondents talk about may not be as important as what they assume or do not apprehend. Charmaz (2000 p 514) sums up the situation succinctly by saying, "an acontextual reliance on respondents' overt concerns can lead to narrow research problems, limited data and trivial analyses."

A further problem can arise if the data are treated as though they have objective status, for example - "the data do not lie" (Strauss & Corbin 1998 p 85). But data are reconstructions, whether from interview accounts or from stories reflecting experience, such as that contained in personal diaries, private journals, reports etc. Data for this study are drawn from three sources: a questionnaire, an interview and from concept maps drawn by the respondents. These multiple sources are intended
to maximise richness and allow triangulation to occur, with a hoped for increase in validity.

**Coding and categorising data.**

Data is coded as it is collected, the codes themselves being created as the data are studied. The aim of coding is to give a new perspective on the material, through defining and categorising it. Generating codes facilitates in the making of comparisons, which is a major technique in grounded theory methods. In this study, data comparisons are made between different individuals, and, also, comparisons are made between the data obtained by different methods from the same individuals. The categories for explaining the data arise from the codes - and each category may subsume several codes. In turn, the categories shape the developing analytic frameworks.

**Memo writing.**

This is an intermediate step between coding and the first draft of the completed analysis. It allows the codes to be explored and expanded so that they take on substance and structure. The aim of the memos is to help the researcher see interrelated processes rather than static, isolated topics. I have found them useful for noting down emerging trends and tentative suggestions.

**Theoretical sampling.**

This technique of returning to examine and, or, produce more data in order to fill conceptual gaps revealed as the categories are refined and developed, is considered a defining property of grounded theory methods. It has the aim of refining ideas and not simply increasing the size of the original sample. It is the mechanism by which a theory develops and becomes formalised. The process is repeated until 'saturation' - new data fit into the categories already devised, when the memos can be expanded and rewritten in more analytic form. Where it is not possible to return to collect new
additional data, the study may be informed by examination of an alternative source; the approach being used in this study, where three sources of data are used – questionnaire, concept map and interview. An example from my study can be seen in Chapter 7 (Theme 2, issue No. 3) where progressive focusing on participants during interviews revealed the existence of an informal network of co-operation between them which was previously unsuspected. This kind of revelation of what could be new lines of enquiry is illustrative of one of the advantages of qualitative research over quantitative methods.

The nature of the method and its limitations, have not been without critical challenge. Richardson (1994), for example, identified selectivity in choosing evidence and the adoption of value-laden metaphors, as particular weaknesses. More fundamental criticism comes from both Conrad and Riessman (in Charmaz 2000 p 521), who suggest that the process of 'fracturing the data' (by creating codes and categories as themes defined within the data) in grounded theory methods might limit understanding, because the aim is for analysis, rather than the "portrayal of subjects' experience in its fullness" (Charmaz 2000 p 521). Yet Glaser and Strauss (1967) proposed this strategy in order to create a way for the researcher to organise and interpret data.

The separation by Charmaz (1995) into positivist (objectivist) and phenomenological (constructivist) approaches affords a way of focusing on the implications of the methodology chosen. Grounded theory studies typically lie between traditional research methodology and the more interpretive, contextually situated approach. Objectivist grounded theory accepts the positivistic assumption of an external world that can be described, analysed, explained, and predicted. It is based on the assumption that, following a systematic set of methods leads to the discovery of reality and to the fabrication of a provisionally true, testable and, ultimately verifiable,
"theory" of it (Charmaz 2000 p 524). The approach provides both understanding and prediction, but at the cost of seeing the methods as being a set of prescriptive rules. Terms and categories take centre stage, and the observer is distanced from the 'experience', rather than having their attention concentrated on it.

By contrast, constructivist grounded theory recognises that, "the viewer creates the data and ensuing analysis, through interaction with the viewed" (Charmaz 2000 p 523). What a viewer sees, will shape what he or she will define, measure, and analyse, and is a part of it rather than being separate from it. But although a constructivist grounded theory attempts to define conditional statements that interpret how subjects construct their realities, these statements do not approach some level of generalisable truth. However, by offering both explanation and understanding, with positivist assumptions at least partially reconciled to postmodernist critiques, qualitative traditions are being fostered through the study of experience.

The question of how to make a choice from these two approaches is not left to the whim of the researcher, but is resolved on the principle that the research method must serve the question, and not dictate what the question is, or what questions can be asked.

My principal research question ('how do adults learning science respond to new information?'), which uses concept maps as a prime indicator of type of learning, lends itself towards an objectivist approach. The subsidiary investigation, of a possible link between a conception of learning as viewed by the learner, and the type of learning that actually takes place, utilises both objectivist and constructivist aspects of grounded theory methods. Lastly, the issue of whether learners can be helped to become meaningful learners by changing their conception of learning, is one which it is appropriate to consider within the constructivist model.

Though the traditional literature contains relatively few examples in which
methodological procedures are constructed that really integrate qualitative, and
quantitative, strategies in one method, the two approaches are more often combined
nowadays. In the sphere of analysing qualitative data, Kuckartz (1995) describes a
procedure, in which dimensional analyses lead to definition of variables and values,
which can be used for a classification and quantification, though this is not being
attempted in this study. The whole area of validation through different
methodologies, is explored in more detail in literature on triangulation (Flick 1992 and
Flick 2002).

The limitations of both Novak’s concept of learning as a process, and of Marton and
Saljo’s (1984) approach to discover conceptions of learning by interview, have been
referred to at the beginning of this chapter. My approach, in using Novak’s concept
maps, plus interviews and a questionnaire, allows the use of an integration strategy
as a means of searching for a unified explanation of how adults learning science
respond to new information.

The concept of triangulation, as applied, for example, in GPS (Global Positioning
System) technology, is not a package that is transferable into the social science
arena. So, measuring the same phenomena from different angles or positions, with
the aim of getting an accurate reading or measurement, is problematic because it
implies a view of the social world in which there is one, objective and knowable social
reality. Thus, the ‘products’ of different methods may not corroborate each other,
because each may be illuminating different social or ontological phenomena (Mason
2002 p 190). However, by integrating the three methods I am using (concept maps,
questionnaire and interview), I believe the validity of the research to be enhanced. At
the same time, it is sensible to note of the cautionary views of McCormick and James
(1983) that there is no guarantee that a number of data sources that supposedly
provide evidence concerning the same construct will ever do so. Though complete
consensus among data must be unlikely, if incongruent sets of data do emerge from the different instruments, they will either have to be accounted for in some way, or used as the basis of a further hypothesis.

8. SUMMARY

In this chapter I have tried to show how theory and practice inform and support each other in the preparation for, and execution of, a research study. It commenced with a description and critique of concept maps – the metacognitive tool, being the central instrument used. Some contextual issues were explored, and an appreciation of the importance of quality matters is reflected in the more thorough treatment of those matters. A justification of the adopted methodology is linked to awareness of some of the potential problems that accompany the gathering and analysis of data. The next chapter covers both the presentation and the analysis of this data.
CHAPTER 6

RESULTS and ANALYSIS

1. INTRODUCTION

It is appropriate at this point to remember that the view of knowledge creation adopted in this thesis is that it emerges as a product of an interaction between people. Different interactions will give rise to different results; the results are thus created by the interactions, as opposed to being discovered as already 'out there'.

The Danish Nobel science Laureate, Niels Bohr, argued in his 'Complementarity Principle', put forward in a lecture to the International Physical Congress held at Como in September 1927, that the results of any study depended upon the interaction between inquirer and object, i.e. the findings of any study depend as much on the nature of the questions asked and on the order in which they were asked, as on any intrinsic properties of a "real" reality "out there".

The principal question being asked in this study is, 'how do adults learning science respond to new information?' Twenty eight students spread over three different courses participated in the field work, further details being included in Chapter 5. The results are set out in the following pages, and data produced by a selection of those who participated in the study have been used, both to illustrate the process of the analysis, and the findings of this process. Each one illuminates a particular aspect of the learning process and/or, the analysis, and these points will be the subjects of comments in their appropriate contexts. Collectively, these respondents support my contention that they are representative of adults learning science.
2. RESULTS and ANALYSIS

All participants (each referred to by pseudonyms) were given basic training in the drawing of concept maps, plus a copy of the instruction notes (courtesy of University of Surrey) to be found in Appendix 6. It is recognised as inevitable that some learners will not identify with this method of portraying knowledge, but each was asked at interview if they experienced any particular difficulties with this method. They were not shown examples of the different types of concept maps (spokes, nets and chains), but their training identified link quality as important, because cross links indicate integrated knowledge.

Regarding the content of the various lessons used in the study, examples of material used in teaching the basic understanding are included in Appendix 9.

The empirical material in this, and any sociological study, is determined substantially by decisions pertaining to the method of choosing the sample of participants, because sampling strategies describe ways of disclosing a field. The need is to select a sample which will be rich in relevant information. The choice is between representing the field in its diversity - by using as many different cases as possible in order to obtain evidence on the distribution of ways of learning, and permeating the field and its structure - by concentrating on a few examples. Thus, width must be weighed against depth, but the appropriateness of the sample chosen can be assessed only with respect to the research question of the study. Concerning this study, I did not know what there was to discover, and so started with a small number of participants, recognising that the field may have to be widened if no pattern emerged. The case study approach emerged as a promising strategy for analysis, and the six examples selected for presentation in this thesis, from a total of twenty eight, were chosen for diversity within the group of participants available to me.

Concerning the reasons for choosing to present these particular examples as case
studies, it is important, firstly, to dispel any ideas that I am relying on specific cases to support a theory. A trawl of all the evidence collected fails to show any variation in the pattern of response to new information that could be identified as being due to age, gender, course being studied, educational background, or disposition to learning. I decided, therefore, to select examples for inclusion which would illuminate particular characteristics of the respondents, because such illumination would present an opportunity for differences to emerge in response to new information. Thus, Heidi and Jonathan were similarly aged students on the same course, but had rather different dispositions to learning — the characteristic for comparison here. Nathaniel, not at all articulate, unless on anything to do with soccer, had caught my attention by his ability to transfer to the field of science, his understanding of the difficulties of correcting errors and, or, misunderstandings as they related to the 'beautiful game'. Much of what he knew had come from his coach, and I was interested to see how he responded to new information. Clare was typical of many of the adults who enrol at the college — a single mother juggling many challenges, demands and worries, yet making time to satisfy a perceived intellectual need. I expected her to be accustomed to 'multitasking' and to have developed efficiency in her learning; this might make for interesting comparison with those who had, on the face of it, less complex domestic environments. Sally with her unconventional upbringing, and absence of institutionalised education, might be expected to respond more uniquely to new knowledge, whilst Penny was a much more academically experienced learner than the others; it would be interesting to see whether she exhibited responses to new information that could be identified with an intellect that had been subjected to more formal development.

I had plenty more data relating to other respondents, and was ready to pick up on any instances that suggested differences in response to new knowledge, but, as the thematic analysis given in Chapter 7 demonstrates, none of the characteristics
referred to above appears to influence the response of an adult to new information as presented in science courses. Further supporting data are included in Appendix 8.

1. HEIDI

Heidi is a twenty year old with GCSE in Science and other subjects, and is following a Pharmacy Technicians course at National Certificate level, on a day release scheme. She is conscientious, with a methodical approach to all she does, and enjoys her work as a technician in the laboratory of a large hospital in the West Country. She lacks confidence and attributes this to having two brothers, who are older than she is, and who excelled in science at school. She said that, "without always being aware of it, they intimidated me and I lost confidence, so science became difficult for me". After having received tuition and practice in writing concept maps, and following a two or three minute 'brainstorming' exercise, Heidi produced a concept map on acids:

This map is useful only to show that Heidi has picked up sufficient from the training to be able to transform a few simple concepts into a map. The link words are adequate, and a hierarchical structure is present, with two layers included. The map identified a base for Heidi, both in terms of her ability to draw a map, and in establishing her background knowledge of the topic. There followed about thirty minutes of teaching, mainly didactic, with a small amount of individual practical work.
to illustrate the concepts of indicators and neutralisation. Heidi then wrote a new concept map:

Fig. 11 Heidi’s 2nd Concept Map on Acids – based on initial teaching

Heidi’s new map indicates an apparently secure grasp of the concepts covered in the teaching, and four levels have been included in the hierarchy of concepts. The lack of any cross links suggests either, that the knowledge is held in linear structures, or that there is a lack of confidence or expertise in concept map drawing. The map could have included several cross links if a slightly different arrangement had been adopted – see Chapter 7 for an example.
One week later, the teaching session began with a five minute interactive recapitulation of the topic covered previously. Some concepts were then extended after identification of the limitations of explanations that had been given in the teaching of the previous week. Heidi then produced a revised concept map incorporating the extended knowledge:

![Concept Map](Fig. 12 Heidi's 3rd Concept Map on Acids - incorporating extended knowledge)

The linear format continues and there is still an absence of cross links, but the significant feature is the retention of the 'old' concept of acids containing hydrogen, alongside the introduction of the 'new' concept of acids being substances which contain an excess of hydroxonium ions. 'Old' and 'new' concepts appear to be held in parallel, and in a written end of unit test some weeks later, Heidi showed she had in fact retained both 'old' and 'new' knowledge. It is appropriate here, at least to attempt to explain why I might expect 'old' knowledge to be dropped. In my experience, there is an expectation among teachers, and trainers, that they can so
manage the learning of students that they will absorb those things required of them, and unlearn, or reject, other things. But, my expectation is not evidence based, it is, in fact, the opposite of this; because there is evidence (Piaget & Inhelder 1974, Pine & Messner 2000, Barker 2000a) that it is very difficult to unlearn knowledge – this point is explored further in Chapter 7. Yet, the management of learning as it is imparted to those in training, makes the assumption that misconceptions and, or, errors etc. can be abandoned by learners.

At interview, Heidi said “rote learning is better for me”, whereas in discussion she had volunteered that learning “allows you to do something for yourself”. She also said that she had gone through school relying on putting all her effort into memorising, rather than understanding, in order to learn, though she was fairly sure that she did “come to understand lots of things eventually”. When asked why she did not just forget the elementary ideas within a subject, when they came to be replaced by complex explanations that allowed a more comprehensive understanding, she said: “I'm afraid to forget anything in case I might need it again”, and, “I may understand it better than the more complicated explanation”.

As noted above, Heidi is, by nature, conscientious. She views all information given in a teaching situation as important, even precious. She appears to make no effort to discriminate between different pieces of information, and seems to regard it all as too valuable to ignore. She learns by rote because, for her, it is a tried and trusted method. Her experience is that her understanding develops over time, so she shows no frustration at any initial non-understanding. Not surprisingly, physics – where progress is linked more directly to the understanding of a few principles – was a stumbling block for her at school. She dealt with this by avoiding the subject as far as possible (not impossible in combined science courses), and by “learning the descriptive bits really well".
2. JONATHAN

Jonathan is a twenty-four year old with GCSE's that include a Double Award in Science. He is in his first year of a National Certificate course for Pharmacy Technicians, and volunteers that he is intellectually lazy, although he harbours a belief that he could achieve anything he wanted. He has a casual attitude, and is careless over matters where precision, and being systematic matter. After a series of "unrewarding" jobs, his father had helped him to obtain his training post as a technician in a hospital laboratory situated on the South Coast of England. He seems to resent the job because it was not something he was able to obtain unaided. Jonathan's father is a professional scientist working locally; a responsible and respected public servant whose achievements and standards Jonathan feels he is unable to match. His interests (music and pool) did not offer career prospects, and Jonathan said he felt "trapped", although he had no specific yearnings: "I have all I need".

Jonathan produced his first concept map after initial tuition and practice, plus a two to three minute 'brainstorming' exercise on the subject of 'acids':

---

138
Fig. 13 Jonathan's 1st Concept Map on Acids

This map, like the one drawn by Heidi, is essential only to show that Jonathan is capable of drawing such a map. There are no significant differences from the one which was produced by Heidi. After approximately thirty minutes teaching, with some practical work to introduce the concepts of indicators and neutralisation, Jonathan wrote a new concept map:
ACIDS

contain can be

HYDROGEN

which can be replaced by

METALS

to form

SALTS

can be

WEAK

with

FAIRLY LOW pH

shown by

UNIVERSAL INDICATOR

NEUTRALISED

by

BASES

which have

HIGH pH

can be

STRONG

with

VERY LOW pH

Jonathan's map is dominated by linear structures and uses simple link words. Cross linking is absent but, as with Heidi, there was scope for it to have featured (see Chapter 7 for an example).

Jonathan's map, revised to incorporate extended knowledge, after further teaching one week later looked like this:
Fig. 15 Jonathan's 3rd Concept Map on Acids – incorporating extended knowledge

The significant feature of this map of Jonathan's is the inclusion of both 'old' and 'new' concepts in parallel linear structures. A cross link reinforces the intention to integrate new with old, and the link words suggest the concepts are understood – though not yet to the point of replacing the 'old' concepts by the 'new' ones.

In interview, Jonathan said he disliked the effort it needed to memorise, and preferred to understand things. When challenged that his maps suggested that he used memory more than he was acknowledging, he suggested that he "memorised what he understood". He thought it was a "bit of a lottery" as to what was retained and what was discarded.

Jonathan's disposition to learning is complicated by his attitude to both his job and his father. Though he suggests his preference for understanding is simply because it involves less effort than memorising, I think it may be related to a natural curiosity – I had observed that he liked to understand things. Jonathan's suggestion that he
memorised what he understood is a typical remark – he enjoys defending his position, and often comes up with interesting ideas.

3. NATHANIEL

Nathaniel is a nineteen year old, with a Double Award in Science at GCSE level. His interests centre around sport, and he hopes to train in physiotherapy, having lost a place through injury in a West Country professional football team. He is intelligent and willing, but has a short attention span and poorly developed communication skills, though he can think creatively. Around half way through his Access to Higher Education course, he was observed by a 'head-hunter' from a football team in the United States while playing in the local league. He was offered a place in a football team in the United States which was linked to a place on a course at the nearby university. And so, Nathaniel went on his way.

Whilst still a member of the Access Course, Nathaniel drew this map after class discussion on the topic; the subject matter was, 'Chemical Bonding and Related Properties':
ATOMS

join with each other forming

BONDS

which can be

COVALENT

have

LOW MPts

since

BONDS ARE WEAK

where

ELECTRONS ARE SHARED

IONIC

where

IONS ARE ATTRACTED

have

HIGH MPts

because

BONDS ARE STRONG

Fig. 16 Nathaniel’s 1st Concept Map on Chemical Bonding and Related Properties

This is another map dominated by linear structures with an absence of cross links. An important factual error is revealed at the bottom of the chain on the far left-hand side – covalent bonds are not weak, and low melting points are due to weak forces holding small molecules together, although this is not relevant to this study.

After teaching, Nathaniel redrew the map to include the new knowledge:
Fig. 17 Nathaniel’s 2nd Concept Map on Chemical Bonding and Related Properties - incorporating extended knowledge

Nathaniel’s map after ‘new’ material had been taught appears quite comprehensive at first glance but, a) it is still composed of linear patterns with no cross linking, b) the factual error persists, and c) the new knowledge, which was taught as extending the covalent bond concept, has been separated out and presented in parallel in the first vertical column on the left-hand side of the diagram. A further misconception has been generated as a result of this - that the three forces not previously mentioned are nothing to do with covalent bonds.

In interview, Nathaniel said that at school he had always relied on “thinking on my feet” (an interesting use of language for a footballer), whereas now he attaches more
importance to understanding the theoretical content of a lesson, rather than to a spontaneous response; but he did volunteer that his old habit is still "there to help me out". On being asked about discarding old and irrelevant knowledge, Nathaniel said that this was difficult for skills as well as for knowledge, because, "once it's there you can't get rid of it".

Once he had made the connection between learning science and learning football, Nathaniel became much more animated in the interview. He had learned from previous experience that learning a flawed method in a technique or manoeuvre causes problems, because of the difficulty involved in correcting the error. In his world of rapid responses to fast changing situations, Nathaniel said that it "didn't matter whether the knowledge was understood or held in memory, just the speed and accuracy of the response". I reminded him that learning something, and the application of that learning, are not the same thing, although application is an aspect of learning. Nathaniel is versatile and does seem able to utilise both the techniques of rote and meaningful learning.

4. CLARE

Clare is a twenty seven year old, with a GCSE in Science, who has endured a menial but convenient job while her children were young. Taking advantage of more freedom to attend to her own development, she joined the Access to Higher Education class, in order to "see where my interests and abilities are, or are not". She showed some initial talent and enthusiasm for chemical analysis, until an occasion when she became very tearful during a practical class. She was holding a test-tube containing a colourless liquid and repeating the words, "I can't see anything there". I did wonder if the process of analysis had become a vehicle for her to peer into her life, a life which she had deconstructed in similar fashion to the chemical substance. She completed the course and is now reading Applied Biology at university.
After recall discussion in class, and training in concept map writing, Clare drew this map, which relates to the structure of matter:

![Concept Map](image)

Fig. 18 Clare's 1st Concept Map on the Structure of Matter

There are some errors in this map which is formed of linear patterns and lacks cross links. The errors are that, on the left-hand side the pure substances need not be
Following teaching to extend knowledge on atomic structure, Clare drew this map:

Fig. 19 Clare’s 2nd Concept Map on the Structure of Matter – incorporating extended knowledge

Here, the link between elements and nucleus and electrons is confusing, and almost certainly covers a misconception. When I asked Clare at interview to tell me what she knew about the structure of matter, her confusion regarding atoms and elements became apparent. I gave her a short tutorial on the topic, and then asked her to draw a concept map to illustrate her understanding as a result of this additional instruction. She changed only the link words, leaving the hierarchical order unchanged. It was not a new map which may have indicated how very difficult it is to
change understanding. The map is dominated by linear structures and, while Clare has made some attempt to incorporate the 'new' knowledge, clarity is lacking in respect of the principle that governs the filling of shells. Thus, the '2 or 8' box, referring to the number of electrons in orbits, has been retained, with an extension added to cover the larger atoms in which there are more than sixteen electrons. Here, existing knowledge has been added to and not replaced. Clare said she would like to learn meaningfully, but has always had difficulty in "retaining her understanding". She thinks she understands something in class but, "when I get home it's gone". So she has to resort to memorising, regardless of whether or not she understands the material. Clare is hoping to make some progress towards more meaningful learning in this course. Initially, she says, forgetting is very easy for her but, on reflection she admits, the knowledge is "in there somewhere".

Clare views understanding as something that has to be memorised, hence her reference to "retaining understanding". She says she has never thought about the process of learning until now, and she would quite like to learn how to learn. Arising from a hierarchical view that meaningful learning is 'better' than rote learning, she places herself on the bottom rung of the learning ladder. Slowness with knowledge retrieval, and a fragile self-confidence, seem to be factors that are a hindrance to any progress beyond rote learning for her at the moment.

5. SALLY

Sally had spent most of her thirty four years living with her parents on a motor sailing boat in various parts of the Mediterranean. Her parents had bought the boat from the proceeds of the sale of their home and possessions when Sally was a very young child, and it had provided the means to an alternative lifestyle. Sally had been educated by her parents who generated income by casual work in boatyards and cafés. Sally described her parents as being very attentive to her academic
development; she was certainly outwardly self-confident (especially in languages) with an unusually broad perspective on life. She had enrolled on an Access to Higher Education course with a view to obtaining a qualification with international recognition (in nursing), and then to return to life on the boat.

Although Sally said she had received encouragement from her parents for her plans, she was troubled by the possible consequences of "daring to contemplate being different from them". She recognised that she could succeed in academic work, but that success could lead her away from her parents for ever; whereas failure, which almost seemed to beckon her as she became increasingly anxious about the dilemma, would return her to the life she knew, and in which she had been very happy. Sally may, or may not, have resolved her problem but, however, she did continue with the course, and was offered nurse training at the hospital of her choice.

Sally described herself as a meaningful learner but, because she had no previous experience of theoretical chemistry, it was not possible for her to draw an initial map. After teaching, the map she drew shows clear understanding and is without factual errors. She demonstrates competence in the procedures of concept map drawing and uses a variety of link words. Her map has been included because it shows that the knowledge I have described as 'further knowledge' can be incorporated into a concept map without having to include the 'earlier knowledge' in it. For Sally, this was all "new knowledge". Sally defended the memorising of routines as being essential in boat craft, "when the weather's bad and, or, you are very, very tired". She also said that she "kept alive" knowledge which had "once worked", and continued to do this unless, or until, something failed repeatedly to be of use. Then it would come to mind as a "route not to go down", although, she claimed, the knowledge would still be retained. Sally illustrated her point with examples from boat craft. This is the map that Sally drew:
Penny had, at twenty two years of age, withdrawn from a mathematics degree course in a college of a prestigious university at the end of her second year, having had every prospect of achieving a high classification in the honours stage. Her withdrawal had been against the advice of parents and tutors but at the request of her boyfriend, who convinced her that she was "losing her femininity" by living in the
“man’s world of maths”. Penny had, accordingly, enrolled on a HND Media Make-up course for which she showed, what I thought to be, an exaggerated enthusiasm. She had related these details to me by way of explaining her attitude to the module that I delivered: “science is a bit close to home for me”. She seemed indifferent to the practical side of the course but was unable to avoid pouncing on any intellectual challenge (see comment at end of next paragraph).

In the Descriptions of Learning Questionnaire, Penny described herself as embracing every type of learning which was identified in the list. When I raised this in interview, she said she had “never had any problems with learning”, was lucky to have accurate recall and the ability to understand things without difficulty. Her concept maps tend to confirm this, and it is interesting to note that new learning has been bolted on to existing learning and has not replaced it. Penny’s only comment about this was to say, "well, the knowledge was there so I put it down". It is worth noting that Penny included the mathematical formula in one of her concept map boxes – students had been given this information by way of explaining the principle, but told it was not essential understanding at this level.

Penny’s first map drawn after recall stimulus is within the subject matter ‘Atomic Structure’:
Fig. 21 Penny’s 1st Concept Map on the Structure of Matter

Penny’s first map uses a variety of appropriate link words, but it does not contain all the information given, e.g. no mention of the electrical charge of the electron (negative), or of its mass relative to the mass of the proton and neutron. However, it does demonstrate competence in the drawing of a concept map, and adequate understanding of the subject matter at the stage before new knowledge was introduced.

Penny modified her map after new teaching which included reference to the Periodic Table, transition elements and the formula \(2n^2\) for calculation of the maximum number of electrons which can occupy a shell.
The foregoing results are all concerned with the responses of adults to new information in science as this is revealed through concept maps. My study also asked each participant to complete a 'Descriptions of Learning Questionnaire' (a copy of which is included in Appendix 1) in which each participant could indicate with which conception(s) of learning (Marton 1988) they most clearly identified.
Of the six conceptions, the first three, i) increasing one's knowledge, ii) memorising and reproducing knowledge, and iii) applying knowledge, carry no notion of meaning in themselves and are each identified with rote learning. The other three, iv) understanding, v) seeing something in a different way, and vi) changing as a person through learning, are each identified with meaningful learning.

The results are suited to coding, and so the letter 'R' is used to refer to the first three conceptions and the letter 'M' to the second three. The questionnaire revealed that the participants indicated themselves as corresponding to: Heidi - R, Jonathan - M, Nathaniel - R & M, Clare - R, Sally - M, Penny - R & M.

My intention had been to use a similar system of coding in order to consider the type of learning indicated by concept maps and drawn by the same respondents. This would test the link between the conception of learning as seen by the participant, and that which the concept map shows to be actually taking place. However, as will be discussed in the next chapter, all respondents would be classified as rote learners due to the absence of cross links in the concept maps, and so the intention could not be carried out.

3. SUMMARY

In summary it can be stated, regardless of all other factors, for example, disposition to learning, background in science, age, gender or type of course, that the foregoing data have demonstrated that new information does not immediately supplant or replace existing information, but is accepted alongside the latter. Also, that the new information may not be integrated initially with prior knowledge, and that misconceptions are not easily shed.

A full discussion of the findings follows in Chapter 7.
CHAPTER 7

DISCUSSION OF OUTCOMES

&

CRITIQUE OF THE WORK

1. INTRODUCTION

While the case study style of presentation was used for setting out the results, a thematic style will be adopted for this discussion. Three themes are identified, 1) learning science, 2) adults learning, and 3) conceptual change. Each of them will be examined, firstly by a brief summary of what is known and accepted about them, secondly by considering the evidence from my research, and thirdly by critically reflecting on how that evidence relates to the literature on the subject.

The model used for interpretation of the findings is Ausubel's theory of cognitive learning (Ausubel 1968), which is explained more fully in Chapter 4. This describes learning in terms of a process in which new information is related to an existing relevant aspect of an individual's knowledge structure, and support for this theory is widespread in the field of education. Munn's study (Munn et al 1992 p11), relating to mature students on science, mathematics and engineering courses, is an example of this support. Her report states that, "adults .... like to relate material to that which they already know".

The critique aspect of this chapter will consider both the strengths and weaknesses of the research project, while the summary will focus on the significance of the findings, and enable a link to be made with the conclusions that are drawn in the final chapter.
2. DISCUSSION and CRITIQUE

Theme 1: Learning Science

Accepted understanding

When considering what is known about learning science, it is important to make clear that the learning of science is not being compared with learning other disciplines (though one might expect some relation to other disciplines), nor is it appropriate to examine or defend the commonly held assumption that scientific rationalism is preferable to alternative traditions. It is worth noting, however, that science offers a distinctive way of acquiring knowledge by the methods it uses for getting results. Many would argue that these results testify to the excellence of the method, but this debate also occupies territory outside the scope of this thesis. Instead of learning based on tradition, science offers knowledge based on experience, though to what extent science could, or should, become the foundation of our culture is also not under consideration in these pages.

Many of the factors relating to learning per se, apply equally to learning science, an example being that of the crucial role of existing knowledge in assimilating and describing new findings (Munn et al 1992 p12). The provisional and uncertain status of scientific knowledge is, however, not common to all types of knowledge, nor is the practice of encouraging learners to accept the knowledge of the time, without there being any attempts to justify or validate it.

A contribution which is pertinent to our knowledge of the learning of science was made by Stavy (1990) whose findings included that the reasoning which takes place when a substance being scrutinised remains visible, is different from the reasoning which occurs when the substance is invisible (whether with magnification or not). Perkins et al (1993) identified two problems faced by learners of science: 1) they must possess the competence to reason critically, 2) they must be able to dislodge
their existing beliefs from evidence presented in the problems; the difficulties of doing this were referred to in Chapter 4.

It should be pointed out here that, although the methods of recording and comparing knowledge that the participants have learned by questionnaire, concept map and interview are behavioural, nevertheless, some of what was learned is an example of cognitive learning. However, it has to be acknowledged that, because students of science below higher education level are learning to conform to the accepted position in terms of scientific knowledge, much of the teaching is behaviourist in nature. It may be rapidly changing knowledge, but, mostly at this level, it is taught as if it were unchanging fact – so the learners default to conformist positions; whereas, students of science at higher education level would be expected to possess more appreciation of the provisional nature of scientific knowledge.

Research evidence

i) Correlation between integrative reconciliation and meaningful learning. First on the list of indicators of expertise in concept maps (included in Chapter 5 and drawn from Kinchin et al 2000) is the characteristic of link quality. Experts are expected to produce highly integrated structures with numerous cross links, whereas novices tend to produce maps which are dominated by linear arrangements. The description 'expert' would be at one end of a continuum and might apply to a teacher, whilst the term 'novice' would be at the opposite end of the continuum and might apply to a learner with no experience of the topic. The terms 'expert' and 'novice', ignore expertise in concept map construction, this being considered a constant factor among learners with no previous experience of concept maps. While this may be an acceptable assumption, it does ignore any variation in aptitude with a new skill such as concept map construction – this is a limitation in the design of this study, and although some may argue that the use of more participants in the study would show the extent of this, there is no logical reason why sampling from a larger population
should produce a ‘better’ picture. A total of 28 adult learners participated in my study.

Novak (1998 p63-65) is unequivocal in his claim that, a consequence of meaningful learning is the appearance of progressive differentiation and integrative reconciliation in concept maps. These feature as cross links, but Novak does not explore whether these links are necessary or sufficient conditions for meaningful learning. Certainly, they are absent in nearly all of the concept maps drawn by my students, yet they had been told during concept map training that, the ability to recognise opportunities for inserting cross links into their concept maps represented a desirable level of integration of their knowledge, and that they should aspire to this. Thus, taken on its own, Heidi’s second concept map, illustrated in Chapter 6, in which there is no attempt to insert cross links, might indicate that she was not confident in the use of concept maps, or it could indicate that her knowledge was not integrated and was held in isolated linear compartments. There were opportunities for adding cross-links into this map, as my re-drawing of her map, below, illustrates.
Taken with her declared (at interview) faith in rote learning, her second map is valuable evidence that her knowledge is held in compartments, and that she does, indeed, learn by rote. This is supported yet further by the questionnaire, in which Heidi indicated that she chose to learn by rote. Heidi had, during schooling, worked out strategies for coping which were based on memory, being confident that understanding would quietly take its place at some later stage. Her habit is to retain what has been learned, and to use problem solving as a means of honing discrimination: "if the rules I think of first don't work, then I try what comes next". Set against this background, Heidi's concept maps appear to be a clear illustration of her methods of learning. She sees no need to change her strategies, indeed the risk associated with such change has little to commend it – why should she exchange
something that has “always worked so far”, for something unknown?

Jonathan had declared himself a meaningful learner in the questionnaire, yet the second of his concept maps (illustrated in Chapter 6) is dominated by linear structures and includes simple link words. Cross links are absent in his second map, although he did include one in his third map - the map which incorporated his extended knowledge, and the link words used in the third map do suggest the concepts are understood.

Jonathan is on the same course as Heidi and is of a similar age, although very different in his outlook and attitudes. He is casual, whereas Heidi is conscientious; he appears not to value his job, whilst Heidi considers the setting of her work in a hospital, with its career prospects (modest) and status (also modest), as a major part of her identity. Heidi stands by rote learning, whereas Jonathan claims he can only learn in a meaningful way, but his claim does not appear to be reflected in his concept map. Those who declare themselves to be rote learners in the questionnaire and in the interview, produce concept maps that use simple link words and have no integrative reconciliation. The declared meaningful learners, on the other hand, were unable to substantiate their claims in their concept maps - which indicated that, either they had learned by rote, or, possibly, they were novice concept map constructors. If the latter is the explanation, I would have expected to find that some were showing indications of ‘expert’ ability, but this was not the case.

A comment by Penny, who had drawn her concept maps very quickly, although she had no previous experience of using them other than the training I had conducted, was cause for reflection. When I raised the issue of cross links with her, pointing out that they were taken as indicators of integrated knowledge, and that she had not included any, she said: “Oh! I'll do you a map with some cross links, if they’re
important". Although Penny had considerably more intellectual maturity than the average student passing through a college of Further Education (she had completed two years of a maths degree course), her comment was unsettling. It raises general issues about teacher expectation in terms of responses during assessment, and challenges the claim by Novak (1998 p 64) that integrative reconciliation is consequent on meaningful learning. Perhaps it is, but you still may have to ask for it to be demonstrated, which weakens the claim somewhat.

In summary, it seems that, though there could be doubts about Novak's claim that crosslinks are consequent on meaningful learning because we do not know what part they played in the initial training he gave to students on concept map drawing, nevertheless, it does appear that when taken with interview evidence it is possible to claim that adults respond to new information in science by rote learning, initially at least.

ii) Use of the word 'supplantive' when describing learning. Atherton (1999 p78) claims that "most learning, even in the case of adults, involves simply adding to one's stock of knowledge or skill, hence the label 'additive'". The term 'supplantive' is also used by Atherton, replacing his earlier terms 'threatening learning' (Atherton 1986 p78), and 'traumatic learning' (Atherton 1991 p78), but he appears to use the terms 'additive' and 'supplantive' synonymously with 'surface' and 'deep' in a paper (Atherton 1999: p78) based on participants in in-service professional training programmes. Although Atherton does not define his term 'supplantive', the word is self-descriptive, and he contrasts it with the word 'additive', so I do not think there is much doubt about the meaning he intends to convey by using it. I would not consider using the term 'supplantive' interchangeably with 'deep' when describing learning, because 'supplantive' implies that replacement has taken place, and this is not the case where the knowledge is entirely new. Thus, to my mind, 'supplantive' is a category of knowledge, and could be 'deep' - as in the case of Sally, or 'surface' - as
in the alteration of the purchase price of an article, or the change of a code number.

My findings indicate that replacement of knowledge does not immediately take place. This was a surprise to me, since it is an expectation of those teaching science that simple 'scaffolding' knowledge will fall away as the edifice of new and more complex knowledge is put in place. The limitations and inadequacies of an individual's previous knowledge are a usual starting point in teaching a topic, and new information is then developed to explain more adequately the complexities of observed data. To discover that all the 'old' knowledge is retained was unexpected, as teachers and trainers tend to proceed on the assumption that 'old' knowledge can be replaced, and replaced immediately. Thus, new knowledge is added to what is already known, and, whilst this is not actually in conflict with Ausubel's (1962) assimilation theory of learning (new knowledge is related to an existing relevant aspect of an individual's knowledge structure), this draws attention to a misinterpretation of his theory, namely - that new information replaces the old.

iii) Concept map interpretation. The evidence of the concept maps would suggest that much rote learning has occurred, both by self-confessed rote learners such as Heidi, and by declared meaningful learners such as Jonathan. Whilst one could challenge Novak's claim that meaningful learning is always accompanied by integrative reconciliation, his findings are well established, and it would be surprising if a flaw of this proportion had not been revealed before. Bringing evidence from the interviews which I conducted into the picture suggests another possibility, namely, that mostly, or maybe always, new learning is additive and, therefore, not what Novak would describe as meaningful. This idea is certainly supported by the concept maps, all of which show that new knowledge is added -bolted on - to existing knowledge. It would require a longitudinal study to confirm this, and I regret not being able to pursue this. There is circumstantial evidence that this 'additive' learning is meaningful, at least to some extent; for example, i) evidence from
interviews – it does not take an experienced teacher long to assess whether a student understands what he, or she, is talking about, ii) evidence from pre-experiment planning exercises, where some aspects of an hypothesis are going to be investigated and, or, tested, and iii) evidence from written tests and home study exercises. Whilst the weight of evidence from any one of these sources could be challenged, it is submitted that, when considered together they add up to something not insubstantial. In other words, the use of additional sources of evidence in conjunction with concept maps, reduce reliance on an individual source at the same time as achieving some increase in the validity of the conclusions drawn.

Critical reflection

Considering how the evidence relates to the literature, both Novak and Kinchin (one being the initiator and the other an enthusiast for concept maps) are convinced there is a direct link between cross linking and meaningful learning. My evidence, which has been gained from adults learning science, is sufficiently equivocal to prompt a look at other possible explanations. For example, i) my research is with adults, whereas most of the published work relating to concept maps has been with children of primary and secondary school ages and, therefore, transferability of results cannot be assumed. ii) An assumption built into my methods (and also into those of Novak and Kinchin - in so far as it is possible to determine), is that meaningful learning displaces old learning without delay. For the various examples of material used for learning, and selected for my research, the time period over which the topic was taught, the questionnaires completed, and the interviews conducted, never exceeded six weeks, and was often nearer to four weeks. These were modular style courses, with assessment having to occur within the term, or semester, during which the topic was covered. It occurs to me – and this is mere speculation – that a temporal dimension is involved with, possibly, new learning held in conjunction with old learning for a period of time, before the former replaces or ‘swamps’ the latter. Such
an idea would, of course, need to be tested, and it would be interesting to see if both
children and adults behaved in similar ways, or not.

Though he writes about ‘supplantine’ learning, Atherton does not offer any evidence
of it having occurred. He writes (Atherton 1999) about in-service professional
training programmes, where there may, or may not, be procedures in place in order
to follow up and to monitor behavioural changes. My findings, relating to learning
science, suggest that new knowledge does not, immediately, replace old knowledge.

While Atherton (1999 p78) acknowledges that, “most learning, even in the case of
adults, involves simply adding to one’s stock of knowledge or skill ....”. Novak
(1998), on the other hand, promotes meaningful learning as the only kind of learning
that is worthwhile (other than for recalling telephone numbers). My research findings
show that much rote learning - some by intention and some regardless of declared
intention - occurs by adults learning science when judged on the inclusion, or not, of
cross links in concept maps. At this stage, I wish to avoid trying to establish a claim
that rote learning is worthwhile, but I do believe it is necessary to consider the
possibility that it is an essential link in the process of learning becoming meaningful.
My evidence indicates that new learning by adults in science is, at least initially, not
integrated into the learner’s knowledge system – but added to it, nor does it replace
previous learning. To call it ‘rote’ learning may be misleading, but the term ‘initial’
learning or ‘first response’ learning may identify it more precisely.

Theme 2: Learning by Adults

Accepted understanding

Considering what is accepted about the way adults learn, while there is an
abundance of literature on teaching adults, especially with regard to vocational
education and assessment, there is less on the ways in which adults (specifically)
learn, and some research findings need an improved model within which to explain
them. For example, Ramsden et al (1986) found that, study skills training for those undergraduates who learn by surface learning methods, succeeded only in making their surface learning strategies more sophisticated, rather than developing deep learning strategies. The Armed Forces have a long tradition of implementing behaviourist principles by conditioning in the training of adults, and similar ideas underlie some approaches to therapy that have been used extensively with adults, but these approaches have been used with skills training rather than with cognitive learning.

Much understanding about the way children learn has been gained through the work of the cognitive theorists, the most influential being Jean Piaget, though his work did not extend beyond adolescents. Neugarton (1977) identified an increasing use of reflective thinking in adulthood, and Riegel (1973) focused on the fact that adults think in a way which results in the discovery of important questions and problems. Mezirow's name is often quoted when adult learning is discussed, perhaps because he was an adult educator, but he was not concerned with the actual process of adult learning, more with meaning schemes and perspectives. Jarvis (1987), one of our foremost constructivists, distinguishes between non-reflective and reflective learning - but not according to age, recognising that adults may be non-reflective learners in which memorizing features prominently. Malcolm Knowles (1970), who introduced the term andragogy, as being the art and science of helping adults learn, used experience as pivotal when considering the ways that adults and children can learn; namely, that adults use their experiences as the basis of their learning, whereas children learn from being taught. The idea seems to take no account of adults being taught by methods similar to those used with children, and this muddied the water of Knowles' andragogy versus pedagogy distinctions. Schauble's (1996) work is a modern summary of what is known about adults learning, but in this she focuses on the outcome of their learning, rather than on the methods by which they learn;
further, that adults make more valid inferences than do children, but that these inferences show the existence of early errors. Candy (1981 p 63) argued that, the one feature which is consistently held up as the identifying characteristic of adult education (Candy did not say adult learning), is the propensity of adults to be self-directed.

Research evidence
Looking now at the evidence from my research, it is relevant to state that this was not a study comparing the learning of adults with children (interesting though that might be). Three issues are selected for discussion:

i) The role of memorising in learning. A feature of the learning by the adults attending my classes was the extent to which they used, and relied on, memory. Interviews suggest that, for some at least – for example, Heidi, this was related both to conformity to their own expectations, (they had decided that this is what the subject would require) and to fear of not ‘losing’ the understanding they had, or thought they had, in the classroom, for example, Clare. Many were avid note takers, and it was not uncommon at the end of a lecture to be asked to supply a word or phrase that a student had not managed to record – as though every word was essential. All of the concept maps indicate accurate recall, and Novak would, no doubt, say they are good examples of where rote learning has occurred. An example is Sally’s concept map (reproduced on page 180) which she constructed by memorising both the data and the sequencing of it.

It is perhaps too easily forgotten that the classical art of memory was considered a crucial mental attribute which was revived in the later medieval and renaissance periods, and that it linked the eye and ear through remembered speech. Bantock (1980 p 43) describes this classical art which implies a capacity, under training, for the development of an intense capacity for internal visualisation; the visual structure emphasised and reinforced the mental one. The importance of memory was noted by
Fig. 24 Sally's concept map constructed by memorising the data and the sequencing of it.

Francis Bacon who wrote (quoted by Yates 1969 p 358): "what is sensible always strikes the memory stronger, and sooner impresses itself than the intellectual ....". In more recent times, Marton and Saljo's (1984) phenomenographic approach revealed that students who viewed learning as the acquisition of knowledge utilised memorising to meet their needs.

In a study comprising an investigation of the epistemological beliefs and study habits
of students undertaking first year courses in Biological Chemistry and Biochemistry, conducted in 2004, Watters and Watters (2007) report that respondents speaking about their beliefs about learning, used words such as "if the exam is quite near then I have to memorise it" (p 32) and "at first you had to memorise the basics ..." (p 34). A number of these students had a strong orientation for memorisation that seemed to have evolved because they had found memorisation to be important for success in high school (in Australia). It seems that the learners who participated in my study are not untypical.

ii) The placing of new knowledge as revealed by concept maps. Reference was made in the previous theme (Learning Science) to the fact that new knowledge is added to the existing store and does not immediately, at least, replace it. The comments there are equally applicable to this theme. Nathaniel's map, reproduced below, shows how the 'new' knowledge (1st column) appears alongside the knowledge gained earlier (2nd column), and has not replaced that knowledge.

A comment by Martin (1994) that teaching concentrates on one sequence of ideas after another, without demonstrating the links between them prompts the thought that this would result in learners producing concept maps that are dominated by chain arrangements. As has been pointed out in Section 3a of Chapter 5 of this thesis, chain structures which are less flexible than spoke structures, which are more resistant to disruption. Thus, it could be argued that basic teaching should be presented so the resulting knowledge conforms to a spoke-like framework as this allows inclusion of new material with greater ease. A legitimate objection would be that this approach stands or falls on the applicability of the chosen model, and further work would be needed to be sure that it could be employed in a wider context.
iii) Co-operation between adults in learning. An aspect of self-direction (not itself a feature of adult learning that was being monitored) was evident in three out of the four programmes involved from which participants in this study were chosen. Self-direction might well have been present in the fourth group, but this was the first group interviewed, and the existence of co-operation was not something of which I had been aware. As Knowles had observed, self-directed learning is usually a co-operative exercise: "there is a lot of mutuality among self-directed learners" (Knowles 1975 p18). The existence and extent of this co-operation was revealed in the interviews – often in tentative, almost apologetic tone; for example, "I hope you don't mind, but some of us get together after your lectures and go over what we had done"
(Clare). In laboratory work as well, it was noticeable that there would be conferring
between small groups of students. When I raised the question of co-operation with
others in the group with Sally, she was more open about it as an experience not
expected by her, and from which she was able both to gain and to contribute.

One possible contributory factor to the positive comments about their co-operation
with each other, offered by the research participants, is the lack of texts suitable for
the science modules of the various courses which they were studying – they may
have needed this co-operation in order to reinforce their learning. Some learners did
find material that was helpful on web sites, whereas those who used texts from the
College Resources Centre found these unsuitable in one way or another - “too
technical”, “too advanced”, “unreadable”.

Critical reflection

When I first examined the concept maps and noted the absence of cross linking, I
was inclined to attribute this to my failure at enabling meaningful learning to have
occurred. Further reflection suggested a variety of possible explanations, including:
i) the learner not being confident with the use of concept maps, ii) the learner not
being motivated sufficiently to build cross links into map, iii) the knowledge is not
integrated and so cross links cannot be provided, iv) the teaching and, or, learning
had been aimed at compartmentalised knowledge, and so cross links are not
considered important by learner, v) the assessment does not cover any integrated
knowledge, vi) rote learning has been encouraged, and so cross links are not
applicable, vii) Novak is incorrect in associating cross links with meaningful learning,
viii) new learning is always initially ‘additive’, and ix) the learner is intended to
memorise and not to integrate the new knowledge. Using the questionnaire and
interview in triangulation indicates that, in some instances, no. 4 may be true, but the
concept maps point clearly to no. 8 being the underlying reason for the absence to
cross linking. This is supported by those studies, for example Schauble (1996), which
found that there is reluctance and/or difficulty in abandoning what has been learned previously. It would be interesting to study both the process of transfer of reliance from 'old' to 'new' knowledge, and the timescale over which this transfer takes place.

The evidence of learners co-operating with each other is supported by the literature, for example, Henschke (1994:49) writes: "...interaction with others in small groupings that helps them internalise information...". There was no evidence of what Benn (1994 p49) describes as, learners "not having their learning needs met through formal education", therefore, the co-operation was not prompted by what the learners considered was 'bad' or 'inadequate' teaching. Kilpatrick, Bell and Falk (1999 p131) say that "learning can (and frequently does) occur when individuals and groups interact", therefore suggesting that, learning occurs through interactions between individuals, as well as between individuals and groups. They (Kilpatrick, Bell & Falk 1999 p131) also claim that, "the quantity of the social processes and relationships within which learning interactions take place is especially influential on the quality of the learning outcomes in informal learning". Co-operation and informal learning are areas which have been fairly extensively researched and, generally, are considered beneficial to all involved, although Benn (1994a p 49) is right to caution about the discontinuity between formal and informal learning. My only reservation about informal learning, that students acquire from work place or hobby sources, concerns possible misconceptions that may arise from experience unsupported by theory. Sometimes the misconception can be cleared easily by supplying the theory, but there are times that, the 'evidence of experience' becomes 'set in concrete', and this can present a hindrance to progress (see 'barriers to learning' in Chapter 4)

Though I attempted no measurements to judge the impact of this co-operative learning, I was alert to identify any disadvantages that might be arising from it. For example, I looked particularly to see whether those whom I had recognised as having weakness in mathematics were improving their skills or 'hitching a ride' in a group.
My impression was that most adults were gaining in both understanding and confidence through co-operative learning, though a few would use the opportunity to support them in their aversions and weaknesses. The limitations identified by Brookfield (1989 p 161) concerning self-directed learning, namely, that it can be too comfortable and allow existing assumptions and prejudices to go unchallenged, seemed not to apply with co-operative learning. Hence co-operative learning is better to overcome conservative tendencies which let new learning reinforce old patterns.

Theme 3 Conceptions of Learning

Accepted understanding

Any alteration to existing knowledge involves altering concepts, or acquiring new ones. Falk and Harrison (1998 p609 – 627) developed the idea that learning has two components: its process, and the outcomes of that process. This is useful here, because change is an outcome of the process, and it can be observed. This contrasts with Lundvall’s (1992) argument, that change is a cumulative process which builds on existing knowledge and practices. The researchers’ who have written on types of conceptual change, though they may use differing terminology, seem to agree that there are two basic kinds of change. Thus:

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Terms used to describe learning type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atherton (1999)</td>
<td>Additive</td>
</tr>
<tr>
<td>Botkin et al (1979)</td>
<td>Maintenance</td>
</tr>
<tr>
<td>Brookfield (1987)</td>
<td>Non-critical</td>
</tr>
<tr>
<td>Jarvis (1987)</td>
<td>Non-reflective</td>
</tr>
<tr>
<td>Novak (1998)</td>
<td>Rote</td>
</tr>
<tr>
<td></td>
<td>Additive</td>
</tr>
<tr>
<td></td>
<td>Maintenance</td>
</tr>
<tr>
<td></td>
<td>Non-critical</td>
</tr>
<tr>
<td></td>
<td>Non-reflective</td>
</tr>
<tr>
<td></td>
<td>Rote</td>
</tr>
</tbody>
</table>

Marton et al (1989 p 283), identify six conceptions of learning; three of these do not contain notions of meaning - increasing one’s knowledge, memorising and reproducing, and applying knowledge, whilst the other three do imply that meaning is present - understanding, seeing something in a different way, and changing as a
person through learning.

Jarvis (1999 p 38) argues that all learning begins with an experience of disjuncture, which occurs when there is disharmony between a person's constructed experience of a situation and their biography. So, a disjunctural situation is a potential change situation from which one can learn. The problem is that while current conceptions provide a framework that a learner can use to interpret and understand new information, it can potentially constitute momentum that resists conceptual change. This paradox that exists for the learner has been explored by Pintrich, Marx and Boyle (1993).

Barriers to the development of learning are common to all types of learner and in any type of learning; and they can vary in origin, from issues relating to the learning environment, to personal experiences in the lifetime of the learner. The work of Boud, Cohen and Walker (1993), Atherton (1999), Tytler and White (1996), Klaczynski and Narasimham (1998), and others, has been referred to in Chapter 3. The barrier that I encountered most frequently in those who participated in this study, and in others who did not, was a lack of self-belief and confidence. The learners often managed to overcome formidable obstacles in areas of finance, accommodation, transport and health, yet when confronted with an elementary (for example, secondary school year 9) problem in physics, their other problems seemed mere trivialities. Fortunately, in many instances, these 'Berlin Walls' were not immovable.

Research evidence

Considering the evidence both for conceptual change and for resistance to it, the questionnaires provided the opportunity for the participants' answers to a question about the conception of learning with which they identified most strongly. One of the intentions behind this research was to see if the self-assessment matched
the conception of learning identified by examination of the concept map, using the idea advanced by Novak (1998), that meaningful learning can be spotted from the presence of cross links (integrative reconciliation). Contrary to expectation, I found that none of the participants inserted cross links, although there were other indicators that the learning was not entirely without meaning, for example, interviews, end of module tests, pre-experiment planning exercises, and even the link words used in the concept maps. Thus, a question to Penny about the fact that her concept map specified the equality of mass in the nuclear particles, but omitted any reference to the mass of the electron, brought an immediate and confident response - "Oh! But it has negligible mass and the mass of the atom is concentrated in the nucleus". This indicated to me that her learning had been meaningful. Although the evidence indicates that all learning in science by adults is initially not meaningful learning, I suspect that meaning, and therefore integration of the knowledge, develops over time. This is a clear reminder that it would have been a mistake to have built this study on reliance of concept maps alone for evidence. However, as the design involved gathering data from three sources, namely, concept maps, interview, and questionnaire and, considering only what was suggested by examination of all of the data together, I do not think that Penny's comments undermined the methods in any way.

It is inevitable when considering conceptual change that, any resistance to such change, and the factors responsible for triggering the resistance, will need to be considered. Evidence for barriers to learning was gathered at interview, in questions that were focused on difficulties relating to learning science. Although respondents were not discouraged from talking about "situational" (Atherton 1999 p 86) factors such as administrative failures etc., nineteen out of the twenty eight participants in my study reported difficulties with texts, such as reading and being able to understand the texts, and being able to pursue an inquiry. Although many were
accomplished in their abilities to access information via the internet, the skills required to do this are not identical to those needed in order to use the index of a book.

Twenty two of the respondents expressed some degree of apprehension about their study in science. Mostly, they did not have positive memories that could have fuelled self confidence, and even those who showed every indication of having a secure grasp of what had been covered, seemed to be 'waiting for the catch'. Fifteen of the twenty two feared they had an inadequate foundation on which the new material could be built.

Critical reflection
Considering ways in which this evidence relates to the literature, it does not appear that Novak’s (1998) claim that cross linkage is indicative of the type of learning that has taken place, has been supported by this study. It is quite possible that a temporal dimension exists in the process of adults responding to new information and that my respondents drew their maps before it had become integrated with other knowledge. Further study would be needed to test this.

Referring to the fear of failure through a lack of background knowledge, Munn et al (1992 p 40) found that five out of nine failures mentioned lack of background knowledge; this was from a total of nineteen Higher National Certificate physics and engineering students, and with the term ‘failure’ here describing performance in the assessment process as being below that deemed necessary in order to proceed further with the module and, or, course. My data does not refer to failure, rather to anxiety about being able to succeed, but it seems that, for some, the anxiety is well founded. Munn et al (1992 p 11) dug more deeply into this, and found that a particular aspect of the foundation needed by learners on which to build is familiarity with basic concepts. Students whom they questioned said how difficult it was to come to grips with abstract knowledge, about electricity, for instance. Interestingly,
most of the adult learners involved in my study had studied some science to GCSE level, although they were generally weak on basic concepts, and were not confident in accessing information from texts. One of the conclusions reached by Munn et al (1992 p 26) in their final section, on what providers could do to help adults cope, was to encourage students to acquire study skills. Lack of confidence and fear of failure feature prominently as obstacles to learning and there may be a widespread need for upgrading the study skills in most adult learners.

3. SUMMARY

The findings of this study are interpreted in terms of the model provided by Ausubel's (1968) assimilation theory. This theory, although framed within the perspective of cognitivism, is broadly compatible with social and pragmatic learning theories in its focus on interaction and its central stress on the environment. Commonalities exist in the academic histories of all the students who participated in this study; they arise from science being a compulsory element in the National Curriculum. However, their dispositions to learning and their social histories are often quite different, yet there is a surprising constancy in the way they learn. It seems that new knowledge in science is learned by adults — initially at least — in a non-reflective way — by rote or as surface learning. This is not in conflict with the constructivist approach, as new understanding can amount to an enlargement of existing understanding, as much as to replacement of it. There is no evidential support that 'new' learning displaces 'old' learning without delay; however, knowledge that is already established is retained, at least for some weeks. There is, also, no evidence that conceptions of learning are other than as declared by learners, but because all 'new' learning appears to be other than fully meaningful, it has not been possible to test the link between these declared conceptions of learning and the conceptions indicated by their concept maps. Adult learners co-operate voluntarily with each other and benefit from this co-operation; they tend to have anxieties about the extent and state of their background
knowledge, and experience difficulty in using standard texts. Learning can be hindered when barriers are triggered, some of the barriers and triggers being specific to adults.

Knowles asserted that adults are taught like children because adult teaching methods are based on theories about child learning. He argues (Knowles 1990) that teaching adults is different from teaching children because adults bring motivations, goals, expectations and experiences to learning situations that are different from those of a child. He stated as self-evident-truth that the techniques for teaching adults must reflect those differences (Knowles 1990, p 27-65). Jarvis (1994, p 61-63) has pointed out that the distinction between andragogy and pedagogy is not sustainable when related to biological age, but there need be no difference in the way Knowles envisaged between teaching adults and teaching children. Jarvis also suggests (Jarvis 1994 p 63), that there may be a difference in vocational education which relates to levels of experience of the learners, thus initial vocational learners have no experience within their vocation and so are pedagogic learners, whereas continuing vocational learners do have experience, and so the teaching needs to be appropriate – what Knowles would call andragogy.

It seems to me that when Knowles (1990, p 120-125) writes about the importance of the teaching environment, that this is really to do with barriers to learning and not to some more fundamental difference arising from chronological age. Also, it seems possible that Knowles proposed his techniques for teaching adults without discovering whether or not they were equally effective when used with children. Though my experience with teaching children has been entirely with children above eleven years of age, I have always found that such elements as collaboration, mutuality, respect,
and experiential techniques as opposed to transmittal techniques, to be far more effective than the authority-orientated, formal, competitive approach that Knowles identifies with pedagogy. Knowles does not refer to his direct experiences with teaching children, and he may be making assumptions which contrast rather conveniently with his alternative methods. I wonder what he would have made of the finding that adults resemble children in the way that their initial learning of new information is consistently by rote.

Knowles does identify some potentially negative consequences arising from experience, for example, the development of mental habits, biases and presuppositions that can cause an adult to close his/her mind to new ideas, and the risk that if an adult's experience is ignored or devalued, this may be perceived as not just rejecting their experience, but rejecting them as persons (Knowles 1990, p59-60). However, he fails to develop the first of the above examples into the paradox that it is, namely that the very same experiences that can constitute momentum that resists change can be the ones which provide frameworks that the learner can use to interpret new information. Classroom experiences also suggest that more experience can mean existing knowledge (whether incorrect or erroneous) is more deeply entrenched and resistant to change; certainly it will not be abandoned.

I first read Knowle's (1970) work shortly after switching from teaching children of secondary school age to teaching in a Further Education College. The differences between the two age groups (when taught the same course, for example, GCE 'A' level) were not, however, identifiable with those of the andragogical and pedagogical models, but more to do with, for example, excuses for work uncompleted which, in the case of adults, were more often identified with parenting issues and barriers to learning. Issues relating to the process of learning science were very similar in both age groups and I was
never convinced that Knowles had identified something that is both real and universal. He makes an interesting case and, of course, there are many differences between secondary schools and Further Education Colleges, but my experience does not persuade me that the methods of learning are different. However, my study was with adults and not a comparison of learning between adults and children.

The interpretation of the empirical work for this study is based largely on claims made by Novak; i.e. that long chains without cross linking in a concept map are indicators of knowledge that is not integrated and that the learning is not meaningful. Having examined a number of concept maps produced by my students, I am less confident about accepting such a claim, because if I present an argument or a topic in a sequential style – perhaps in a developmental or historical context, it seems to me almost inevitable that the information will be housed by the learner in that format, at least initially. Thus, whereas I was searching for cross linking as indicators of meaningful learning, I am now of the opinion that, mostly at least, it was unrealistic to expect them. Whilst their absence has rather undermined one of my subsidiary research questions, nevertheless, I consider that an important insight has been gained into the limitations of interpretation of data produced by concept maps.

Novak is very dismissive of rote learning (Novak 1998 p 61), but my findings indicate that most learners (from my samples) use memory to anchor new knowledge. A number of current practices, for example, the modular structure of courses which are examined/assessed on completion of the teaching programme, undoubtedly are supported by the rote learning style. My classroom experience indicates that a transference of knowledge from that acquired by rote, to that which is integrated with other knowledge (thereby
becoming meaningful), tends to occur. The mechanism of, and time-scale over which this transference takes place, need to be investigated.

The comments above do not detract from other useful attributes of concept maps, but an appreciation of their limitations is recommended to both classroom teachers and education researchers.

This study has focused on the responses by adults to new information in science, and may, therefore, be described as being both small and compact. Whilst there are certain advantages to compactness (one can hope to achieve some clarity in answer to a limited range of specific questions), nevertheless assumptions still have to be made. In this case, for example, it is assumed that any variation in aptitude with regard to the drawing of concept maps, will not have interfered with the results. It is also assumed that the selection strategy used to recruit participants is not seriously flawed, and that the results generated by the study are not artefacts of my teaching idiosyncrasies. The triangulation of data from concept maps, questionnaires and interviews has minimised errors of interpretation and strengthened the validity of the study, as well as revealing interesting nuggets of dissonance. These nuggets act as valuable reminders that not everything a learner knows is necessarily going to be put into a concept map. As always data must be the subject of critical scrutiny.

There are implications to some of these findings. If adults learning science do not learn meaningfully at the time the learning takes place, then modular courses have an inherent weakness when compared to courses which do not include 'short' modules. There may be a tendency by those delivering in-service training courses to think that content should be presented on the assumption that meaningful learning will occur more or less simultaneously with delivery. If the new learning is going to be learned additively, maybe the teaching strategies of these courses should be reviewed with recognition, perhaps, of the need to upgrade study skills. These implications will be considered in more detail in the next chapter.
CHAPTER 8

CONCLUSIONS

1. INTRODUCTION

The summary of the findings of this research, which will also identify the specific contributions to our knowledge about the learning process, will be preceded by some general remarks on assumptions and interpretative problems in science that have some relevance to this study. The conclusions will then be set into a wider context, after which a brief discussion of further work I hope to undertake will be included.

2. ASSUMPTIONS

At this stage of the study it is appropriate to note that empirical testing does not make things right or wrong. For example, it could be true that the most important factor in the successful learning of science by adults is the personality of the teacher. The fact that no adequate research programme, that I am aware of, has been devised to look into this has nothing to do with its truth or falsity. This does, however, have the consequence that all observations of learning strategies must be imperfect, to some degree, in as much as this variable at least, is not under control. Also, there is no reason to assume that things have to be quantifiable to be significant – though this is the basis on which much investigative work in the natural sciences is undertaken.

Patton (1980 p 119) claims that the assumptions which under-gird qualitative research are, firstly, the importance of understanding people and programmes in context; secondly, a commitment to study naturally occurring phenomena without introducing extra controls or manipulation; and thirdly, that understanding emerges most meaningfully from an inductive analysis of open-ended, detailed, descriptive and quotational data, gathered through direct contact with the programme and its participants. However, Morgan cautions by saying that,
attempts to judge the utility of different research strategies in terms of universal criteria based on the importance of generalisability, predictability and control, explanations of variance, meaningful understanding, or whatever are inevitably flawed: these criteria inevitably favour research strategies consistent with the assumptions that generate such criteria as meaningful guidelines for the evaluation of research. It is simply inadequate to attempt to justify a particular style of research in terms of assumptions that give rise to that style of research. ... Different research perspectives make different kinds of knowledge claims, and the criteria as to what counts as significant knowledge vary from one to another.

Morgan 1983 p 14-15

So readers must make their own decisions about the relative value of any given perspective, for there is no universal standard that can be applied to choose among the different frameworks.

It is not only the assumptions which underlie theoretical perspectives in qualitative inquiry that have to be taken account of, for they also underpin every calculation and experiment that is made. An example relates to a calculation made in 1941 by a distinguished Canadian astronomer, that one million tonnes of fuel would be required to take a five hundred gram payload on a return trip to the Moon. However, the strategy employed by NASA in 1969 was to detach the spent part of the rocket as soon as it had completed its task - since only the small capsule containing the astronauts needed to complete the return journey, thus fuel would not be used unnecessarily in transporting the spent part of the rocket to the moon. There was nothing wrong with the astronomer's calculation, only the assumption underpinning it, namely, that the entire assembly had to make the full journey in both directions. There is an important difference in the assumptions made by a physical science experimenter and a sociologist undertaking qualitative inquiry though, and this relates
to what is known as the 'faithful measurement postulate'. This refers to the physical world where, say, an instrument is thrown into a definite state by a specific state of the system it is measuring. Because it is assumed that the same state of the world always produces the same state of the instrument, it is possible to infer the state of the world from the state of the instrument. The point of relevance to this study is that the 'faithful measurement postulate' cannot be applied to questionnaires and interviews - sometimes considered as the analogues of the physical scientists' instruments.

An illustration of how prejudice can affect conclusions may also be taken from the world of astronomy: due (at least in part) to the Wilkinson Microwave Anisotropy Probe (WMAP) satellite, which revealed the density of matter and dark energy in the early universe, most astronomers are confident that the world is flat. But Reich (2009 p15) reports that view is now being questioned by J. Silk, at the University of Oxford, and colleagues, who claim it is possible that the WMAP observations have been misinterpreted. They took data from WMAP and analysed them using Bayes's theorem, which can be used to show how the certainty attached to a particular conclusion is affected by different starting assumptions. The analysis produced a ninety eight per cent probability that the universe is indeed flat but when the calculation was rerun starting from a more open-minded position, the probability changed to sixty seven per cent, making a flat universe far less of a certainty than astronomers generally conclude. Ideally, a case should start to look compelling no matter what the starting assumptions are.

Assumptions featured in the work of the French physicist and philosopher Pierre Duhem (1861-1916) who emphasised that the prediction a phenomenon will occur is made from a set of premises, and that failure to observe the predicted phenomenon falsifies only the conjunction of these premises. He believed that, when disconfirming evidence is produced, the decision about which assumptions of a theory are to be modified has to be left to the judgement of scientists for there is nothing in the logic of
disconfirmation that pinpoints the erroneous part of the theory. Duhem applied his analysis of the logic of disconfirmation to the idea of a "crucial experiment", the existence of which had been suggested by Francis Bacon, and which would conclusively decide the issue between competing theories. In the nineteenth century it was supposed that Foucault's determination that the velocity of light is greater in air than in water, was a crucial experiment, demonstrating not only that light is not a stream of emitted particles but also that light is a wave motion. Duhem pointed out that the Foucault experiment falsifies only a set of hypotheses, and argued (Duhem 1962 p186-190) that an experiment would be "crucial" only if it conclusively eliminated every possible set of premises save one. There can be no such experiments.

Knowles (1990, p63) makes a useful distinction between an ideology and a system of alternative assumptions. He defines ideology as 'a systematic body of beliefs that requires loyalty and conformity by its adherents' and suggests that the pedagogical model has taken on many of the characteristics of an ideology.

In contrast, the andragogical 'model' is put forward as a system of alternative sets of assumptions. The critical difference between the two models is summarised in the statement: 'The pedagogical model is an ideological model which excludes the andragogical assumptions. The andragogical model is a set of assumptions which includes the pedagogical assumptions.' Knowles (1990, p63)

Knowles suggests that, in practice the pedagog insists that learners remain dependent on the teacher, whereas the andragog helps learners to take responsibility for their learning.

Some further comments on Knowles' contribution are given later in the chapter.
3. INTERPRETATION

Teachers may well be interpreters of science, but this research has focused more on the interpretation of science by the learner. An illustration of the difficulties this can cause is seen in a journal article by Mpembra & Osborne (1969), describing an apparently surprising experimental finding. According to the authors, when two beakers of water, at different temperatures but otherwise identical, were placed in a refrigerator and allowed to cool, ice appeared first in the beaker which started at the higher temperature. Thus, if two beakers are taken, containing equal volumes of water, but at different temperatures - one at 100°C and one at 40°C - and put into a refrigerator, the one that started at 100°C freezes first. Moreover, for a given beaker of water, the higher the initial temperature the more quickly ice is observed to form within it when placed in the refrigerator. Thus it appears that the higher the temperature of water in given conditions, the faster it freezes.

The authors were puzzled by the results of their work, which seemed implausible and in need of explanation, for the water in the hotter beaker must do all that the cooler water does, and more, yet in less time. Newton's law of cooling (that the rate of heat loss of a body is proportional to its excess temperature relative to its surroundings) suggests that identical beakers at the same temperature in identical surroundings should take the same time to cool. It would seem that, if the underlying observations were correct, then at least one accepted law of physics must be false.

Barnes has composed a list of possible interpretations of the 'Mpembra effect', the observation that warm water appears to freeze faster than cool water:

1. A practical joke
2. An erroneous set of observations, perhaps due to faulty equipment or confusion of materials. Results not replicable.
3. Result of hot vessel melting into ice, and making better contact with cold refrigerator shelf.
4. Result of heating evaporating water, so that less is left to cool.
5. Something to do with super cooling.
6. Something to do with convection currents in the water.
7. Something to do with convection currents in the surrounding air.
10. Modern scientific world view seriously defective.

Barnes 1985, p 60

It is necessary to consider all possible explanations because the results clash with our existing common sense expectations, which are, in turn, consistent with our understanding of the accepted knowledge of physics. My only reason for introducing the apparently anomalous results of this experiment, is that it illustrates the crucial role of existing knowledge in assimilating and describing new findings. The puzzling nature of the results, as Barnes says (1985, p 61), "derives from their relationship with existing knowledge", namely that they are incompatible with that knowledge. The reliance we place on existing knowledge in making sense of new experiences is brought into focus by consideration of the results of this particular experiment. It also provides an example of cognitive dissonance, the mental conflict that occurs when beliefs or assumptions are contradicted by new information.

Interest in what was formerly a central theme of human psychology, namely that cognitive inconsistency is intrinsically disturbing and demanding of resolution appears to have waned during the last fifty years or so. The drive for mental balance - that our beliefs, attitudes and values must square with our actions - was explored in the 1940's and 1950's and led Heider (1958) to formulate his Balance Theory: that dissonance causes psychological stress and discomfort which motivate behaviour at reducing the gap between the two sets of attitudes, and finding consistency. It was a forerunner of Festinger's (1957) more elaborate cognitive dissonance theory which takes account of the cognitive strategies that let us live with the discrepancies.
between what people do and what they think. Both theories are drive-reduction theories, that is, behaviour that reduces unpleasant physiological arousal, but Festinger invokes the principle of least effort: that we will move in the direction of easiest change, often via a perceptual distortion rather than any fundamental change of attitudes or behaviour. An example from science teaching may be seen in the student who is taught evolution but believes in religious creationism; they do not bother to reconcile these opposing beliefs but just keep them in separate mental compartments.

Reference has been made in Chapter 3 to the fact that some of the information presented to adults learning science conflicts with their existing beliefs or assumptions, and to the ways in which children have been observed to respond to such situations. I was anticipating observing such dissonance being resolved in a variety of ways but, invariably, the opposing beliefs were kept intact in separate compartments (‘mental compartmentalisation’), which mirrored the storage of all new information.

Barnes (1985, p 64) also makes the interesting point that, although we interpret actual situations using existing knowledge, such actual situations - when probed in more detail, are found to be more complex than our interpretations suggest, this indicates that there can be a degree of uncertainty present in our existing knowledge.

Landsberg alludes to this with a reference to adding milk to coffee, that it seems an odd procedure to ‘explain’ everyday occurrences, such as the diffusion of milk into coffee by means of theories of the universe which are themselves less firmly established than the phenomenon to be explained. Most people believe in explaining one set of things in terms of others about which they are more certain and the explanation of normal irreversible phenomena in terms of cosmological expansion is not in this category.

(Landsberg cited by Coveney & Highfield 1991, p 34)
So, the adding of milk to coffee, and two beakers of water in a refrigerator, may seem
to be very simple systems, but if cosmological theories need to be called in to
interpret some observations made about aspects of their behaviour, then a
consequence is that the assessment of new knowledge claims has to be left to the
expertise of a very few specialists; this would have far reaching consequences for the
learning and teaching of elementary science.

Reference was made in a previous paragraph to common sense expectations, and it
is appropriate both to uphold the value of the human instinct in making judgements
about sense experience, as well as to note that there are instances where 'common
sense' had to be discarded in order to gain insight into a problem. In 1905, Einstein
put forward two fundamentally new postulates of physics, one of which stated that
the speed of light is constant and independent of the motion of the light source. The,
seemingly, outrageous nature of this claim is usually illustrated by attempting to
imagine, whether the speed of a rifle bullet fired by a motionless foot soldier is the
same as when fired from an aeroplane cruising at supersonic speeds. Since the
speeds are not the same for the bullets, why should the speeds be the same for
light? Einstein dealt a body blow to common sense by showing that no matter how
fast one observer is travelling with respect to another the speed of light is constant.
Therefore, when adults learning science encounter examples of situations where, for
the first time, their common sense view must be set aside, the experience is
frequently disconcerting for them, and the 'setting aside', or unlearning, becomes
fraught with difficulties (Chapter 3). Common sense, while necessary, is not sufficient
for scientific work.

Another aspect of interpretation that can cause confusion concerns the use of
metaphors as aids to understanding. If a metaphor is taken too literally it becomes a
myth. A scientific myth is "what develops when an imaginative construct becomes
identified with the theory it helps to create" (Turbayne 1970, p 39), an example being that of Descartes (cited by Bréhier, 1966 p 94), 'I have described the earth and the whole visible universe as if it were a machine'. Unimaginative successors of Descartes have taken such words as 'machine' literally, and in so doing have created the myth that the world is a machine.

Bastin (1977 p 126) reminds us that "familiarity makes us see a reasonable coherence where in fact there are great areas of ignorance, while denying any coherence to unfamiliar ideas which may be no worse in their incoherence"

It is appropriate also, at this stage of the thesis to examine and reflect briefly on the nature of discovery and to contrast the type of discovery familiar to science where something that has existed for a long time is first noticed and recorded (for example, that light travels in straight lines), with discovery where the phenomenon is recent and transient, for example, a footprint in sand. In the former case, the data (on shadows) had existed for a long time and is very consistent, while in the latter instance, Robinson Crusoe, we are told, knew the data had not existed twenty four hours previously. Crusoe reached a conclusion by making an inference on the fresh data, i.e. he looked at a new phenomenon in a familiar way. On the other hand, light was discovered to travel in straight lines by looking at a familiar phenomenon in a new way. To attempt to look at the optical phenomenon by using a familiar approach would not result in new insight and Toulmin (1953 p 20) calls this the 'Man Friday fallacy'. Toulmin is making the point that it is not simply a matter of how long the data may have been in place, but that a different inferring technique applied to the optical phenomenon leads to new points of view which permit specific predictions to be made. Thus, from the dimensions of the shadow (which can be measured), can be calculated (inferred) the size of the object which casts it and its distance from the object. Such inferring techniques are the core of many scientific discoveries, which cannot be made from the kind of inference applied to a footprint in the sand. In my
study, I have sought to bring a fresh perspective to a problem that has perplexed people over many centuries, namely, how new and more complex knowledge arises from less complex knowledge.

One further problem with interpretation (in all fields of inquiry) concerns the ability to both use and understand language. Both Kant and Wittgenstein believed it to be easy to stray unwittingly beyond the limits of what language can express, into a kind of "specious nonsense" (Pears 1971 p12) that seems to express genuine thoughts, but in fact does not do so. It would be so helpful if we knew the location of the dividing line between sense and nonsense, but we do not - and this can certainly be an obstacle to communication within some areas of science. McHugh (1970) reminds us that events are transformed into truth only by the application of a canon of procedure, a canon that truth-seekers use and analysts must formulate as providing the possibility of agreement. In other words, we do not consult what a proposition proposes, rather we consult the rules used to decide if what the proposition proposes is warranted.

4. A WIDER CONTEXT FOR THE LEARNING OF SCIENCE

It is appropriate when trying to provide a wide context for a study into learning, to consider what sort of research is research into education. The point is that different sorts of questions will yield differing sorts of answers, and these in turn will offer varying possibilities of validation and probability. Criticism of some modes of research in the social sciences, in which rigour of the methods used has been compared with the so-called exact and natural sciences, has been made by, for example, Wall (1959:3), in spite of a clear analysis by Winch (1958:72). Winch considers a classical exposition of the view that social phenomena are of the same order as physical, only very much more complicated, and involving more variables. He demonstrates its falsity by showing that the natural scientist is governed by only one set of rules, those relevant to scientific investigation, whereas the social scientist
has to take into account another set of rules as well, those involved in the phenomenon she, or he, is investigating. The phenomenon itself will, inevitably, be a manifestation of social activity which is likely to be subject to human purposes and meaning, in a way in which natural phenomena are not. Thus the understanding of social phenomena involves a qualitatively different approach to that needed with natural phenomena, because such understanding implies something more than just external observation. This 'something' is concerned with what the phenomena mean, and this has to come from experience of it, for example, an historian or artist must have "sympathetic understanding" of what it is like to be an historian or artist in order to "grasp what they are driving at" (Gibson 1960, p 47-48). Gibson denies that such "sympathetic understanding" can provide any evidence of an alternative kind to that supplied empirically, but he considers that it places the investigator in a "peculiarly favourable position to give evidence" (Gibson 1960 p 51). I fail to see how I can become my own student in order to be in this position, although I accept that my previous experience of being a student may help me to appreciate how understanding the social and natural world may differ. However, Sorokin (1956, p 159-160), while arguing forcefully that, "only through direct empathy ... can one grasp the essential nature and difference between a criminal gang and a fighting battalion", does not attempt to justify the analogy to educational research.

The ability of the mind to discover new patterns or meanings within the information it already possesses - which may be identified as insight or intuition - does not depend on faultless chains of reasoning. Neither reasoning, nor analysis, can explain the process by which the mind is able to perceive the truth of things, although the knowledge may be fallible, perhaps due to the kinds of assumptions made when we search for an analogy by which to link a current problem to previous experience. Casey (1966, p 17-29) refers to the analogy - or, perhaps to the mythology - of Newton who, in seeing an apple fall, saw the possibility of explaining the movement
of the planets. No new facts had been discovered, but the concept of 'falling' had been enriched by it being applied, for the first time, to the whole solar system. Thus, a new application had been found for the concept of 'falling' and, at the same time, an 'explanation' had been provided of what it is for earthly objects to fall, by connecting their movements with the movements of the planets. This is an example of the power of seeing through an ordinary perceptual phenomenon, to something of which it then became only an illustration. Casey argues that the 'reasoning' behind Newton's perception was neither inductive nor deductive reasoning, as it was not capable of proof. Kant (1790, 1952, p 117) said, that the imagination is "a powerful agent creating as it were a second nature out of the material supplied to it by the first nature". The creative imagination is free from the constraints imposed by the laws of understanding on our perceptions of nature. Kant calls these representations of the creative imagination ideas, because they cannot be apprehended in the appearances of things in the same way that objects that conform to natural laws can be. He uses the word idea in a special sense for something which cannot be experienced directly but for which the imagination "finds an expression and makes it communicable" (Kant 1790, 1952, p 223).

An understanding of the fundamental concepts of science is reached through measurement, followed by insight, and this leads to a grasp of the relations of things to one another. In making such a transition, the learner of science moves from the realm of the imaginable to the unimaginable, the concepts and laws of science being unimaginable and unable to be sensibly apprehended. For example, there is a radical difference between the concept of temperature and the feeling of hotness or coldness. It was recognition of the need to shift from a consideration of the relations of things to the observer, to a determination of functional relations, that marked the difference between Galilean and Aristotelian science; the Aristotelians were content to talk about the nature of something, whereas Galileo insisted that a shift to
explanatory understanding was required.

It is the ability to explain phenomena in terms which are scientifically useful as opposed to merely describing them, that is an indicator of meaningful learning in science. Thus, it is a matter of simple observation that when a rubber sucker is pressed against a smooth surface it requires some force to pull it off, but it requires insight to comprehend, let alone construct, an explanation for this observation in terms of the greater bombardment of particles of gases in the atmosphere on the outer surface of the rubber, compared with the inner surface. A cognitive developmentalist would identify the inability adequately to explain why the sucker sticks, as evidence of the immaturity of the processing mechanism of the person attempting the explanation, whilst an alternative conceiver might emphasise that person's inexperience, and the need to link new experiences to existing conceptions. Adey and Shayer's (1994) study of alternative conceptions theory makes use of Ausubel's (1968) assimilation theory of meaningful learning, in which new knowledge is linked to a framework of existing knowledge. However, Bruner (1998) argues that the cognitive revolution with its fixation on mind as the 'information processor' has led psychology away from the deeper objective of understanding mind as creator of meanings.

One of the confusions that can hinder the process of meaning creation in science concerns the role of the senses in scientific method. Lonergan (1957) argued that the senses provide data and nothing more. Science may begin with observation but its basis lies in data and not facts; facts are reached only at the end of the process of knowing. Because observation yields only data, the problem is to determine the relationship between data and theories, rather than between theories and facts. Insight grasps relations in the data and leads to the formulation of theories, which must then be verified. Verification is not a logical operation, and is quite different
from proof. In the world of science, though, attention has shifted towards verification and away from viewing scientific method as a sequence of logical operations. This trend is evident in Kuhn's (1962) notion of competing paradigms, and Lakatos' (in Lakatos & Musgrave, 1970) notion of competing research programmes, which conditions the way in which problems are solved and meaning is created.

Popper tried to find a demarcation criterion between the scientific and the non-scientific and argued that the theory of falsifiability provided it. The theory proposes that scientific generalisations (including the laws) are falsifiable but not confirmable. While Popper advocates applying the test of falsification to any new proposition as part of the verification process, I found that adults learning science were more inclined to falsify data in order to support present understanding, or predictions based on present understanding, rather than attempt more overtly to falsify a proposition. This observation is confirmed by other researchers, for example Schauble (1996), working with children and adults, as explored further in Chapter 3. It is interesting as an example of a link between the philosophy of science and actual learning as seen in the behavioural approach to experimental science. It would be interesting to look for the existence of other similar kinds of link between philosophy and practical science.

Mention of teaching methods and curriculum content has been avoided deliberately throughout this thesis, but awareness of the possible influence of these factors must now be registered. After decades of research effort in comparative studies of teaching methods, the persistent belief remains that significant differences do exist, yet findings, from Dubin & Tarregia (1968) onwards, proclaim that evidence fails to affirm claimed experiential observations, and theory arising from those observations. It may be that no significant differences are identified, because it is student performance in examinations that are measured, and examinations are generally not related to any definition of learning objectives. Yet there are very great differences
between teaching methods, in terms of student motivation, for example. From a constructivist perspective, learning occurs when learners are actively involved in the process of building their knowledge about the world around them, through physical experiences as well as social interactions. In order to accomplish this, teachers have to be facilitators of the learning process where learners participate actively. If an issue orientated approach is used - which will necessarily be student centred, then classroom activities are also likely to be consistent with constructivist pedagogy.

One of the most significant ways in which teaching has changed during the last decade, is through the introduction of specified learning outcomes for each taught session. Leaving aside the question of whether or not this policy can be shown to have benefits to learners, it seems to me that it could be responsible for learners opting to choose to learn by rote. If these specified outcomes form the basis of assessment, then learners could be more likely to use them in preparation for assessment, and this could explain the extensive use of rote learning by those who participated in my study.

5. CONTRIBUTION TO KNOWLEDGE and PLANS FOR FURTHER WORK
The core question that this research set out to answer concerns how adults learning science respond to new information which, in some cases, is very likely to conflict with their existing understanding. Freud (1958 p 112) cautioned that "if you follow your expectations there is a ... danger of never finding anything but what you already know; if you follow your inclinations you will certainly justify what you perceive". Though the constraints may be formidable, I think a little progress may have been made with the complex problem of responding to new information.

The findings indicate that when new information is presented to adults, it is - initially at least - added to the existing store, and does not supplant it. This response seems to be automatic, although it could be fuelled by teaching styles and assessment
techniques. Adults respond to new information with surface learning strategies, placing considerable reliance on memory, whether or not they declare a preference for meaningful learning. While I have no direct evidence that this approach is a response to increased use of the modular structure of courses, it is an adaptation that is well tailored to this style. Adults learning science co-operate with each other in self-selected small groups, evidence for this being particularly clear where any mathematical processes are required. Barriers to learning are common, and many of these are overcome, although fear of failure, and anxieties over the absence of a sound background understanding of basic science, is volunteered as a problem by most adults.

The results of a study by Watters & Watters – published after I had concluded my research but before completion of this thesis, both complement my study and corroborate my findings. The authors investigated the epistemological beliefs and study habits of students undertaking first year courses in Biological Chemistry and Biochemistry at a metropolitan university in Australia. They found (my numbering):

i) student epistemological beliefs are strongly oriented towards a philosophy that learning involves the accumulation of knowledge that is functional in solving routine-type problems. Approaches to learning are by and large of a surface nature... The common mode of study is memorising...

ii) students have diverse backgrounds ... Few acknowledged experiences in schooling that engaged them in problem solving tasks that would encourage deep learning techniques...

iii) in order to understand new material the activation of pre-existing knowledge is critical. The student needs to reconcile existing beliefs with the new experiences. If the models and ideas held by the student are inappropriate then conceptual change has to occur...

iv) The most salient outcome was the emphasis that students placed on
Watters & Watters (2007 p19-43), who arrived at their conclusions by a mixed method approach that included both qualitative (interviews) and quantitative (surveys and performance records) methods, end their report with the words: "...a better understanding of how biological science students approach learning is needed". With this I concur, and my modest plans for further work are included at the end of this chapter.

The conclusions that emerge from this study illuminate some aspects of the learning process, at least in so far as it applies to adults learning science. Firstly, and in response to the core research question (given in Chapter 5), the study has identified the response of adults to new information as being addition rather than a replacement of existing knowledge. This outcome appears not even to have been considered, or maybe even anticipated by, other researchers. Thus, Stahly et al (1999, p160) posit that 'When children encounter new experiences, or stimuli, the new information may be integrated into existing frameworks; or the conceptions, both new and old, could be reorganised; or the currently held conceptions could be rejected.' The work was, of course, carried out with children, and my study relates to adults; but Pringle (2006, p292), referring to the work of Carin & Ban (1997) and Tolman (2002), makes the point relevant to classroom teachers that, if alternative conceptions are ignored or dismissed, they may persist.

My finding was a surprise to me, as both teacher training and teaching as practised in the classroom is, and has been, based on the assumption that learners will simply abandon ideas and knowledge which may have been held
and perhaps reinforced (in the case of adults) by daily experiences over some years on the basis of an argument presented in a lesson, is not true. This surprise in spite of indications that the knowledge is incorporated in conceptual structures that provide a coherent understanding of the world (Gredler 2001), and the evidence of experience that resides in all adults that we are often resistant to change and reluctant to shed old practices or techniques.

There are implications of this conclusion for both educators and trainers, whether involved in short training courses in skills and/or management, or in longer courses of study. When identifying the intended outcome of their instruction, trainers and educators must accept that learners will not simply abandon what they have known and used in favour of the new information. New information will be added to the store and, at present it is rather speculation to talk about what may happen to it after being added to what exists already.

Secondly, and in relation to the subsidiary research questions (Chapter 5), the study presents a new application of concept mapping, which has been used here for tracking learning rather than as a tool for helping people to learn. In this respect it has proved a useful tool though, based on experience gained in this study, it would be recommended that it be used in conjunction with other tools (in this case the other tools were interviews and questionnaires) and data from all the sources can be triangulated for enhanced validity. The concept maps indicated that adults learning science do so as surface learning, as opposed to deep or meaningful learning. This discovery is supported by the findings of Ramsden et al (1986), who showed that study skills training for first year surface-learning undergraduates succeeded only in making their surface learning strategies more sophisticated, rather
than developing deep-learning strategies.

Thirdly, concerning the issue of whether learners can be helped to become meaningful learners by changing their conceptions of learning, the indications are quite clear that, though learners may aspire to be meaningful learners, they are very resistant to abandoning rote learning where this method has appeared to be effective on previous occasions during their learning history. The findings of Berry & Milroy (2002), Stofflett (1994) and Taber (2001) do suggest that learners' ideas can be reconstructed through teaching if their personal understandings are first uncovered and brought to the surface. All of these studies were based on studies with children and employed conceptual-change approaches to the teaching; such work as would be needed to investigate the effect of such approaches with adults was beyond the scope of this study.

The claims made in these conclusions relate only to adults learning science. It is possible the findings may be applicable to young learners but no claim to this is being advanced. Equally, while it is hoped that, arising from a clearer understanding of hindrances to learning, learners could be helped to conceive of these as susceptible to influence rather than deficiencies about which little can be done, no claim can be made for this on the basis of my study.

Finally, some reflections on the work which will address, firstly, some aspects of research quality:

Early thoughts on this study prompted an awareness that experience should have supplied, namely, how much easier it is to identify limitations and weaknesses at the completion of something than at the planning stage. I am also aware that accepting responsibility for shortcomings does not make this a better study and, in effect, changes nothing. My experience and
understanding have, however, increased and I am more conscious of the
dependence of all kinds of research on philosophy, in that good research is
entirely dependent on good conceptualisation and logical procedures.

Barrow (1981, p 181-183), in a critical appraisal of some research conducted
by Neville Bennett and his associates at Lancaster University on teaching
styles and pupil progress involving thirty seven teachers (Bennett 1976),
highlights a long list of variables that were not, apparently, controlled. These
included the type and background of different children, differences of social
class, different qualities of schools, differences in quality and experience of
teachers, differing aims of teachers etc. He says:

... a great deal of empirical research in education is,
like this, both conducted on so small a scale that its
significance is inevitable minimised, and beset by glaring
weaknesses such as failure to control variables, and yet
its findings are broadcast abroad, without any reference
to such devastating distortions or crucial qualifications as
maybe involved.

Barrow (1976, p 182)

Barrow develops his theme and points out that whilst the work inevitably
furnishes some 'results', these cannot be particularly illuminating because one
knows very little about the causes or reasons for any differences in outcome
observed. He distinguishes between work which is dubbed 'inconclusive' and
that which is just not good enough; in the case he is describing it is the latter
because it lacks a solid conceptual base, i.e. an armoury of precise and
specific concepts. I realise that if one tries to take account of all the subtleties
then it limits what can sensibly be researched into, yet the issues in the field
of education are so complex that approaches that are not rigorous are set
only to disgrace the reputation of both researchers and publishers.
I must hasten to add that, in writing the foregoing, I am not distancing myself from my own study and its results. From reflection on both of these I am more aware of the difficulties involved in researching the field of education. Investigation of the inanimate is easier in some respects, though the construction of instruments suited to the detection and measurement of invisible phenomena has frequently taxed the ingenuity of research scientists.

Secondly, reflecting on the results of my study, and on the explanations constructed from those results, prompts me to reflect on the nature of explanation itself. The aim always is to relate the proposition that is found puzzling, to something that is already known. It is generally assumed, though should always be confirmed, that the recipient of an explanation is in possession of the relevant theoretical and factual background in order to understand the explanation. Thus, an explanation fails if it does not make more intelligible what was previously found to be incompletely understood. Applying this criterion to my study, what was incompletely understood was how new and more complex knowledge can arise from simpler things that were known. The full story has yet to be told, but some new facts to help us along the way have been established, with respect to adults learning science. We have at least moved a distance from Rousseau's constant inveighing against book learning: 'Reading is the scourge of childhood...' (Bantock 1965, p 82, quoting from the Everyman edition of 'Émile, ou Traité de l'éducation' by J-J. Rousseau), and '... Let him not be taught science, let him discover it' (Bantock 1965, p 67).

Thirdly, my views on the ideas of Malcolm Knowles, with respect to adult teaching and learning, and on the concept maps of James Novak in the light of using them in this study, have been set down in the summary to chapter 7
of this thesis. Expressed in briefest form, I emerge from the study with confidence a little less secure, both in the distinction between andragogy and pedagogy, and in the reliability of concept maps as indicators of meaningful learning.

Having shown that adults tend to respond to new information by adding it to their existing knowledge store, rather than using it to replace any of that store, I want now to investigate whether this response is related to the modular style of course delivery, and to trace the development of rote learning into meaningful learning.

Adam and Eve lost Paradise for having eaten of the fruit of the Tree of Knowledge, but they still retained that knowledge. Whilst it is unwise to rest serious research on analogy with legend and symbol, the myth warns us that the wrestling and the exploitation of knowledge are perilous acts. The adult returnee to education is every bit as much a pioneer as the experimental scientist, since both must have a willingness to take risks, and to be intellectual adventurers.
This exercise is aimed at discovering what the word learning means to you. I am here referring to academic learning, i.e. the kind of learning that occurs in academic institutions such as this college. The findings of some researchers can be summarised by saying that learning can be seen as including some of the following, to varying extents:

1. increasing one’s knowledge – adding to the store
2. memorising and being able to reproduce something
3. something that results in the ability to apply some knowledge or procedure
4. understanding, e.g. how things happen or work
5. seeing something in a different way – new insights
6. changing as a person

Based on your own experiences, please indicate your views by putting 'X' marks where these seem appropriate in the diagram below:

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>EXTENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing knowledge</td>
<td>hardly at all</td>
</tr>
<tr>
<td>Memorising &amp; reproducing</td>
<td></td>
</tr>
<tr>
<td>Applying</td>
<td></td>
</tr>
<tr>
<td>Understanding</td>
<td></td>
</tr>
<tr>
<td>Seeing something differently</td>
<td></td>
</tr>
<tr>
<td>Changing as a person</td>
<td>very much so</td>
</tr>
</tbody>
</table>

There are no 'right' or 'wrong' answers here but, if you think these options are incomplete or inadequate, then please give your own description of learning as you have experienced it.
Heidi's completed questionnaire:

DESCRIPTIONS OF LEARNING

This exercise is aimed at discovering what the word learning means to you. I am here referring to academic learning, i.e. the kind of learning that occurs in academic institutions such as this college. The findings of some researchers can be summarised by saying that learning can be seen as including some of the following, to varying extents:

1. increasing one's knowledge – adding to the store
2. memorising and being able to reproduce something
3. something that results in the ability to apply some knowledge or procedure
4. understanding, e.g. how things happen or work
5. seeing something in a different way – new insights
6. changing as a person

Based on your own experiences, please indicate your views by putting 'X' marks where these seem appropriate in the diagram below:

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>EXTENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing knowledge</td>
<td>hardly at all</td>
</tr>
<tr>
<td>Memorising &amp; reproducing</td>
<td>very much so</td>
</tr>
<tr>
<td>Applying</td>
<td></td>
</tr>
<tr>
<td>Understanding</td>
<td></td>
</tr>
<tr>
<td>Seeing something differently</td>
<td></td>
</tr>
<tr>
<td>Changing as a person</td>
<td></td>
</tr>
</tbody>
</table>

There are no 'right' or 'wrong' answers here but, if you think these options are incomplete or inadequate, then please give your own description of learning as you have experienced it.
APPENDIX 2

ILLUSTRATION OF THE DIFFERENCE BETWEEN CONTENT REQUIRED IN 'BASIC UNDERSTANDING' AND THAT REQUIRED IN 'EXTENDED KNOWLEDGE'

REVISION OF SIMPLE IDEAS RE: ACIDS AND BASES

1. Acids are compounds which contain hydrogen that can be replaced by a metal to form a salt.

2. Acids can be weak with a fairly low pH, or they can be strong with a very low pH.

3. Acids can be neutralised by bases, such as sodium hydroxide, which have a high pH.

4. The pH is shown by using universal indicator.

SUMMARY OF EXTENDED IDEAS RE: ACIDS AND BASES

1. Acids are substances that contain an excess of hydroxonium ions $H_3O^+$

2. Bases contain an excess of hydroxide ions $OH^-$

3. When neutralisation takes place, water is formed by the union of the hydroxonium and hydroxide ions

4. A salt is also produced in this reaction. If no replaceable hydrogen remains, the salt will be neutral

5. An acid is an acceptor of electrons
SPECIMEN INTERVIEW TRANSCRIPT

with Heidi = H and Philip Brimson = PB

Line No.
1   PB   Hello Heidi, and thank you for coming in, and for being on time, too.
2   PB   I shall try as hard as I can to remember to call you Heidi all through this interview – which you had earlier agreed I can record – hence this big card with HEIDI written on it in front of me. It’s important because it sets up and maintains your anonymity. You will never be referred to as anyone other than Heidi and only I will know your real identity. If I do slip up, then I will delete the mistake and replay it to you afterwards to show it has gone. Is that OK?
13  H   Yes, that’s OK.
15  PB   Good. Now, if you have any questions about confidentiality or what will happen to the information, then do ask me, either now or anytime in the future. You will be welcome to have copies of everything I write that mentions Heidi. Is that OK?
21  H   Yes, sure.
23  PB   Good. Well, let’s start then, and let me make it clear from the start that in these questions, I’m going to ask you about how you learn and not compare what you do with any ‘right’ way – because that doesn’t exist, yet anyway. So, you are not being criticised or judged, OK?
27  PB   I’d like to begin with the Description of Learning questionnaire you filled in a couple of weeks or so ago – there’s a copy on the table to remind you of it. Now, there are no ‘right’ or ‘wrong’ answers here, but you had indicated that ‘memorising and reproducing’ was by far the most clear way of saying how learning is for you. I just wanted to confirm that that is the way you see it and to ask you to say something more about it.
37  H   Well, umm, where do you want me to start?
Just talk about how you got on at school

OK. Well, I started by really liking science and doing OK in it. But, gradually I found I wasn’t doing so well, it was like I was finding it harder and couldn’t see why. It didn’t help that I had two brothers – older than me – in the same school, and they were brilliant at science, always at the top of the class. I couldn’t match that, maybe I thought the teachers expected me to be like them. My brothers didn’t set out to make it hard for me but, I think without always being aware of it, they intimidated me and I lost confidence, and thought I was thick. So, science became difficult for me.

Did you stop trying or lose interest in science?

Oh no. I was just as interested and determined to do well and stay in the science stream of the school – and, if possible, work in a hospital. I was always fascinated by hospitals when I was little. But I think I began to change the way I worked at it .... I put all my effort into memorising, and found I could do OK in most tests and exams.

Yes, your concept maps suggested that you really depend on rote learning.

I found rote learning is better for me. It’s hard work and my memory’s not brill. But I’ve got used to it and it’s always worked – so far!

How did you manage with physics, for example?

Ah, well, I avoided it as much as I could, but I got by through learning the Descriptive bits really well. I had been put down into the ‘Combined Science’ class – but I think that was because of Maths which I was really rubbish at – and you can’t do stuff you really can’t manage, and still get an OK mark.

Hmm, well, coming back to your concept map, umm it was fine. Was it drawn by rote learning?

Oh yeah.

So, understanding doesn’t really come into the picture much?

Oh, I think I come to understand lots of things eventually. It just takes time and so I have to let it go and not worry about it. I do like to understand stuff but it just takes time for me.
PB So with the 'acids' topic, was there understanding of some of it?

H Yeah. I think I probably understood what's in this map (points to copy of 2nd concept map on the table in front of her). It was when you got to the hydroxy...ummm things, that I didn't understand it. But I could learn it OK for the last map.

PB Do you try to discard or forget the simpler ideas and explanations and concentrate on the more advanced ideas which give better or more complete explanations of things?

H I'm afraid to forget anything in case I might need it again.

PB So, even if I tell you not to use a set of rules, or a way of doing something any more because we've moved on to something that's better in every way, are you saying that you will still hold on to the earlier way?

H Yes.... I think so, it's because I may understand it better than the more complicated explanation. If the rules I think of first don't work, then I try what comes next until I think it's OK.

PB Your concept maps didn't have any cross links - do you remember I mentioned cross links as a way of anchoring in new information so it's linked to other things?

H Yes, I do remember and I think I thought these things are going to confuse me. With memorising stuff, you just need to keep things a bit separated from other things like, otherwise it's in danger of all getting muddled up.

PB Heidi, I think I've almost finished with my questions now. I want to thank you for being so helpful and open about the way you work. It will be a great help in my study. I also want to say that you impress me as a tidy, very organised student who puts a big effort into this subject, and you are managing just fine. Now, is there anything you want to ask me about - either on the discussion we've just had, or about acids, or ....

H I can't think of anything just now, but if I do get stuck I will come and ask you.

PB OK. Well, thanks for your time, and see you in class next week.
### FIELD WORK SCHEDULE

Example of a proposed timetable:

<table>
<thead>
<tr>
<th>Week beginning</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>09/01</td>
<td>First mention</td>
</tr>
<tr>
<td>16/01</td>
<td>2nd mention + recruitment of participants</td>
</tr>
<tr>
<td>23/01</td>
<td>Concept map training + Questionnaire</td>
</tr>
<tr>
<td>30/01</td>
<td>Topic introduced with revision + drawing of 1st concept map</td>
</tr>
<tr>
<td>06/02</td>
<td>New knowledge introduced + drawing of 2nd concept map</td>
</tr>
<tr>
<td>13/02</td>
<td>Interview</td>
</tr>
</tbody>
</table>
## SELECTED BIOGRAPHICAL DETAILS OF SOME PARTICIPANTS

### Course: Access to Higher Education 2005 - 2006  
**Subject:** Chemistry

<table>
<thead>
<tr>
<th>Code</th>
<th>Name</th>
<th>Gender</th>
<th>Age</th>
<th>Previous science education</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sally</td>
<td>F</td>
<td>34</td>
<td>3rd year of secondary school</td>
<td></td>
</tr>
<tr>
<td>Clare</td>
<td>F</td>
<td>27</td>
<td>GCSE Science</td>
<td></td>
</tr>
<tr>
<td>Caroline</td>
<td>F</td>
<td>32</td>
<td>Year 9</td>
<td></td>
</tr>
<tr>
<td>Catherine</td>
<td>F</td>
<td>21</td>
<td>Year 9</td>
<td></td>
</tr>
<tr>
<td>Nathaniel</td>
<td>M</td>
<td>19</td>
<td>GCSE Double Award Science</td>
<td></td>
</tr>
<tr>
<td>Stuart</td>
<td>M</td>
<td>26</td>
<td>Year 9</td>
<td></td>
</tr>
</tbody>
</table>

### Course: NC in Pharmacy Services 2005 - 2006  
**Subject:** Pharmaceutics

<table>
<thead>
<tr>
<th>Code</th>
<th>Gender</th>
<th>Age</th>
<th>Previous science education</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heidi</td>
<td>F</td>
<td>20</td>
<td>GCSE Science</td>
</tr>
<tr>
<td>Clare</td>
<td>F</td>
<td>24</td>
<td>GCSE Science</td>
</tr>
<tr>
<td>Kelly</td>
<td>F</td>
<td>26</td>
<td>GCSE Double Award Science</td>
</tr>
<tr>
<td>Sara</td>
<td>F</td>
<td>26</td>
<td>GCSE Single Science Subjects</td>
</tr>
<tr>
<td>Nina</td>
<td>F</td>
<td>46</td>
<td>None at all</td>
</tr>
<tr>
<td>Lucy</td>
<td>F</td>
<td>31</td>
<td>3rd year secondary school</td>
</tr>
<tr>
<td>Hayley</td>
<td>F</td>
<td>20</td>
<td>GCSE</td>
</tr>
<tr>
<td>Rose</td>
<td>F</td>
<td>28</td>
<td>&quot;very little&quot;</td>
</tr>
<tr>
<td>Rebecca</td>
<td>F</td>
<td>21</td>
<td>'A' Chemistry &amp; Biology</td>
</tr>
<tr>
<td>Jonathan</td>
<td>M</td>
<td>20</td>
<td>GCSE Double Award Science</td>
</tr>
</tbody>
</table>
APPENDIX 6

MATERIALS USED IN TEACHING ON CONSTRUCTION OF CONCEPT MAPS

Supplied by the University of Surrey
MEANINGFUL

to be

LABELS

must have

LINKS

REMEMBER
results in
involved in
needed for
made of
can be
have
is
for
do
are
the
chill! can be hot
work is fun
fire engines are red
CONSTRUCTING A MAP

FAST

RED

FIRE ENGINES
CONSTRUCTING A MAP 3

FAST

RED

999

FIRE ENGINES

are

are

respond to
CONSTRUCTING A MAP 4

FAST
RED
999

FIRE ENGINES
POLICE CARS

Respond to
Respond to
Respond to

ARE
ARE
ARE
A SIMPLE CONCEPT MAP

FLOWERS

Vegetables

Seedlings

GARDEN

GREENHOUSE

GARDENING
Hierarchy of Concepts

Feathers
- Penguins, e.g. robins

Fur
- Cats, e.g. sheep

Marine
- Lobsters, e.g. crabs

Terrestrial
- Flies, e.g. beetles

Blooded
- Warm-blooded

Blooded
- Cold-blooded

Anthropods

Vertebrate

Invertebrate

Animals
LINKS NEED LABELS TO HAVE MEANING!

CHILDREN

get rotten teeth

if they eat too many

SWEETS

CHILDREN

should never eat

SWEETS

CHILDREN

buy

SWEETS

CHILDREN

hate

SWEETS

CHILDREN

like

SWEETS

CHILDREN
Golden rules for concept mapping

1. Concepts are written in boxes
2. Major concepts appear at the top of the page and more specific concepts appear lower down
3. Each concept can only be written in one place on the map
4. Links have arrowheads to show the direction in which they should be read
5. Links must have labels (words or phrases) to give them meaning
6. There can be any number of links coming from or going to a concept box
7. Do not include so many concepts that the overall structure becomes unclear
double helix structure. This maintains the molecule's hydrogen bonding. This is achieved by forming complementary base pairs (A=T & C=G). The bases of pyrimidines (Cytosine and Thymine) and of two types of purines (Adenine and Guanine) and deoxyribose and an organic base. The base is made of phosphoric acid, a pentose sugar made of phosphoric acid and a pentose sugar. Wound round histone proteins. A nucleotide is made up of two strands of nucleotides that are consistent with Watson and Crick in 1953. Each molecule of DNA was discovered by Watson and Crick in 1953.
DNA

Watson & Crick structure (discovered by)

Double helix

Nucleotides

each consists of

Phosphoric acid

Organic base

Sugars

Pentose

Which form can be deoxyribose e.g.

Pyrimidine

Purine

Complementary pairs

e.g. T=A, G=C

H bonding by

Mathematics

Proteins

Histone

In 1953
What does DNA mean to you?
Thus the Gunning Fox Index (first published by Robert Gunning in 1952) gives a good approximation to the readability scores produced by more complex formulae.

The steps for the calculation are:

1. Find the average number of words per sentence. Use a sample of at least one hundred words long. Divide the total number of words by the number of sentences. This gives average sentence length.

2. Count the number of words of three syllables or more per hundred words. Do not count:
   a) words that are capitalised:
   b) combinations of short, easy words - like 'book keepers':
   c) verbs that are made three syllables by adding 'ed' or 'es' - like 'created' or 'trespasses'.

3. Add the two factors above and multiply by 0.4. This gives the Fog Index. It corresponds roughly with the number of years of schooling a person would require to read a passage with ease and understanding.

4. Check the result against this scale:
   
<table>
<thead>
<tr>
<th>Fog Index</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>fairly easy</td>
</tr>
<tr>
<td>7 or 8</td>
<td>standard</td>
</tr>
<tr>
<td>9 to 11</td>
<td>fairly difficult</td>
</tr>
<tr>
<td>12 to 15</td>
<td>difficult</td>
</tr>
<tr>
<td>17 or above</td>
<td>very difficult</td>
</tr>
</tbody>
</table>
APPENDIX 8

Further supporting data – concept maps gathered in the study but not used in the main text of the thesis.
Carol's 1st concept map on 'Chemical Bonding and Related Properties

ELEMENTS

are made up of

ATOMS

which join together to make

BONDS

which can be either

IONIC

which involve atoms

LOSMING ELECTRONS

GAINING ELECTRONS

to form

IONS

COVALENT

here the electrons are

SHARED
Carol's 2nd concept map on 'Chemical Bonding and Related Properties incorporating extended knowledge.'

- **ELEMENTS**
  - are made up of
  - **ATOMS**
    - which join to make
    - **BONDS**
      - which can be
        - **WEAK**
          - and can be
            - **HYDROGEN BONDS**
            - **van der WAALS FORCES**
            - **DIPOLE-DIPOLE FORCES**
  - **STRONG**
    - may be
      - **COVALENT**
        - where electrons are
          - **SHARED**
            - those have
              - **LOW MELTING POINTS**
      - **IONIC**
        - where electrons are
          - **TRANSFERRED**
            - that have
              - **HIGH MELTING POINTS**

all of these have
Catherine's 1st concept map on 'Chemical Bonding and Related Properties'

ALL SUBSTANCES consist of ATOMS which make BONDS by

SHARING ELECTRONS these are called COVALENT and have LOW MELTING POINTS

GIVING OR RECEIVING ELECTRONS which are called IONIC and have HIGH MELTING POINTS
Catherine's 2nd concept map on 'Chemical Bonding and Related Properties' incorporating extended knowledge.
Stuart's 1st concept map on 'Chemical Bonding and Related Properties'
Stuart's 2nd concept map on 'Chemical Bonding and Related Properties' incorporating extended knowledge.

**ATOMS**
- join together making
- **BONDS**
- which can be formed by
  - **SHARING ELECTRONS**
    - PERMANENTLY
      - giving
        - **COVALENT BONDS**
          - these all have
            - **LOW MELTING POINTS**
    - TEMPORARILY
      - making
        - **HYDROGEN BONDS**
          - **DIPOLE-DIPOLE BONDS**
- or formed by making ions by
  - **TRANSFERRING ELECTRONS**
    - these are called
      - **IONIC BONDS**
        - and are
          - **STRONG**
            - because they have
              - **HIGH MELTING POINTS**
Clare's 1st concept map on 'Acids'
Clare's 2nd concept map on 'Acids' incorporating extended knowledge.

ACIDS
contain
HYDROGEN
contain
AN EXCESS OF HYDROXONIUM IONS
and when
NEUTRALISED
they form
SALT
WATER

BASES
contain
AN EXCESS OF HYDROXIDE IONS
and when
Kelly's 1st concept map on 'Acids'
Kelly's 2nd concept map on 'Acids' incorporating extended knowledge.

**ACIDS**
- contain lots of HYDROXONIUM IONS
- contain very few HYDROXIDE IONS
- which together neutralise each other to form SALT and WATER

**HYDROGEN**
- can be neutralised by a base
Code Name: Sara  
Age: 26  
Course: NC Pharmacy Technician  
Subject: Chemistry  
Pre-course science education: GCSE Single Sciences - Chemistry, Physics, Biology

Sara's 1st concept map on 'Acids'

```
ACIDS
  
  contain
  
  HYDROGEN
    which can be replaced by metals to form
    
    SALTS

  can be
  
  WEAK
    with a
    
    FAIRLY LOW pH

  can be
  
  STRONG
    with a
    
    VERY LOW pH

  can be
  
  NEUTRALISED BY BASES
    which have a
    
    HIGH pH
      which is shown by using
      
      UNIVERSAL INDICATOR
```
Old concept retained but an effort has been made to link it into the new concept of acids.
Code name: Nina
Course: NC Pharmacy Technician
Pre-course science education: "none at all"

Nina’s 1st concept map on ‘Acids’
Nina's 2nd concept map on 'Acids' incorporating extended knowledge.

ACIDS

contain

HYDROGEN

which can be

REPLACED BY A METAL

AN EXCESS OF HYDROXONIUM IONS

NEUTRALISE

each other to form a

SALT and

WATER

BASES

contain

AN EXCESS OF HYDROXIDE IONS

these will

247
Lucy's 1st concept map on 'Acids'

**CHEMICALS**

- can be

**ACIDS**

- can be
  - **WEAK**
    - the difference is seen on
    - **INDICATOR PAPER**
  - **STRONG**

**ALKALIS**

- which have a
  - **HIGH pH**

**HYDROGEN**

- these contain
  - and have a
  - **LOW pH**

These can be

**NEUTRALISED**
Lucy's 2nd concept map on 'Acids' incorporating extended knowledge.

- **ACIDS**
  - contain
  - HYDROGEN
    - with a low pH
- **BASES**
  - contain an excess of HYDROXONIUM IONS
  - HYDROXIDE IONS
    - which dissolve in water
- **NEUTRALISED**
  - these can be
  - and can be
  - to produce
  - SALT
  - WATER
Hayley's 1st. concept map on 'Acids'

ACIDS

- Can be
- WEAK
  - Have a
  - LOW pH
    - This is shown on
      - UNIVERSAL INDICATOR PAPER

- Can be
- STRONG
  - Have a
  - VERY LOW pH

- Contain
- HYDROGEN
  - Which can be
    - NEUTRALISED
      - By an
        - ALKALI
          - To form
            - SALT and WATER
Hayley's 2nd concept map on 'Acids' incorporating extended knowledge.
Code name: Rose
Course: NC Pharmacy Technician
Pre-course science education: "very little"

Age: 28
Subject: Chemistry

Rose's 1st concept map on 'Acids'
Rose's 2nd concept map on 'Acids' incorporating extended knowledge.

ACIDS

have lots of

HYDROXONIUM IONS

which account for

LOW pH

and is what is

NEUTRALISED

by

ANTACIDS OR BASES

have

HYDROGEN

which can be replaced by a

METAL

which forms a

SALT

are

STRONG and WEAK

depending on the amount of

HYDROGEN OR HYDROXONIUM IONS
Rebecca's 1st. concept map on 'Acids'
Rebecca's 2nd concept map on 'Acids' incorporating extended knowledge.

ACIDS

- contain

HYDROGEN

- which can be neutralised by

BASES

AN EXCESS OF HYDROXONIUM IONS

NEUTRALISED

- can be

WATER IS FORMED

- when

from

HYDROXONIUM AND HYDROXIDE IONS

BASES

- contain

AN EXCESS OF HYDROXIDE IONS
Code name: Caroline  
Course: HND Media Make-up  
Age: 23  
Subject: Cosmetic science

Caroline's 1st concept map on the 'Structure of Matter'
Caroline's 2nd concept map on the 'Structure of Matter' incorporating extended knowledge.

ELEMENTS

are made from

ATOMS

which have

ELECTRONS IN ORBITS

have

-ve CHARGE

2 IN THE 1st ORBIT

8 IN THE 2nd ORBIT

18 IN THE 3rd ORBIT

32 IN THE 4th ORBIT

NUCLEUS

containing

PROTONS

have

+ve CHARGE

the number of these equals

ATOMIC NUMBER

which together make

NEUTRONS

have

NO CHARGE

MASS NUMBER
Michelle's 1st concept map on the 'Structure of Matter'

Elements

Consist of

Atoms

That are made up of

Nucleus

Consisting of

Neutrons

Protons

Electrons

Arranged in shells with

2 in the 1st shell

8 in the 2nd shell

18 in the 3rd shell
Michelle’s 2nd concept map on the ‘Structure of Matter’ incorporating extended knowledge.

ELEMENTS

consist of

ATOMS

which have surrounding them

ELECTRONS IN SHELLS

with

2 ELECTRONS

8 ELECTRONS

18 ELECTRONS

32 ELECTRONS

which have at their centre a

NUCLEUS

contains

PROTONS

which have +ve CHARGE

NEUTRONS

which have NO ELECTRIC CHARGE

the total of these equals

MASS No.
Sylvia's 1st concept map on the 'Structure of Matter'

- **ELEMENTS**
  - consist of
  - **ATOMS**
    - which have at its centre
    - **NUCLEUS**
      - surrounded by
      - **PROTONS**
      - **NEUTRONS**
        - orbited by
          - **ELECTRONS**
            - arranged in
            - **SHELLS**
              - with
              - 2 in the first
              - 8 in the second
              - 18 in the third

Map contains fundamental errors of misunderstanding.
Sylvia's 2nd concept map on the 'Structure of Matter' incorporating extended knowledge and a tutorial aimed at correcting misconceptions.

Errors have been corrected and map is accurate.
Concept map has identified confusion between proton and neutron. Attempt to introduce cross linking has been made.
Patricia's 2nd concept map on the 'Structure of Matter' incorporating extended knowledge.

**ELEMENTS**
- are made up of a single kind of
- **ATOM**
  - which have on the outside
  - **ELECTRONS**
    - in orbit around the
    - **NUCLEUS**
      - in the centre of which is
      - **PROTONS**
        - containing
        - which normally contain
        - **NEUTRONS**
          - which are
          - **SHIELDS**
            - organised in
            - 1st contains
              - 2 ELECTRONS
                - 2nd contains
                - 8 ELECTRONS
                  - 3rd contains
                  - MAX. OF 8 ELECTRONS

Confusion relating to the role of protons and neutrons has been cleared up.
Chloe's 1st concept map on the 'Structure of Matter'

What has been included is correct, though 'orbits' was somewhat out of place.
Chloe's 2nd concept map on the 'Structure of Matter' incorporating extended knowledge.

This concept map, although it does not repeat knowledge that has not been extended, has built new knowledge on to what pre-existed.
Superfluous hair can be removed by:

- Electrical methods, which include:
  - Electrolysis, which involves using an electric current to kill the root of the hair.
  - Diathermy, which uses an electric current to make heat and kill the root of the hair.
- Dissolving
- Pulling out
- Cutting, i.e.
  - Depilatory creams
    - Wax
    - Sugar
  - Shaving
Sam's 2nd concept map on the 'physics and chemistry of depilation' incorporating extended knowledge of electrochemical methods.

A very linear approach which probably reflects the practical instruction on these techniques.
Julia's 1st concept map on 'Introduction to the physics and chemistry of depilation'

- **UNWANTED HAIR**
  - can be removed by
    - CUTTING OFF
      - using
        - SCISSORS
        - SHAVER
    - PULLING OUT
      - with
    - CREAMS
      - which
        - DISSOLVE HAIR
    - ELECTRICITY
      - such as
        - ELECTROLYSIS
    - WAX
    - SUGAR
Julia's 2nd concept map on the 'physics and chemistry of depilation' incorporating extended knowledge of electrochemical methods.

UNWANTED HAIR

can be removed by

ELECTRICITY

by

HEAT

which is called

DIATHERMY

where the current heats up a probe and

ELECTROLYSIS

where the electricity is taken through a probe into the tissue fluid and

KILLS THE ROOT
Code name: Sabrina
Course: BTEC Beauty Therapy
Age: 18
Subject: Physical sciences

Sabrina’s 1st concept map on ‘Introduction to the physics and chemistry of depilation’.

UNWANTED HAIR

is removed by

ELECTRICAL METHODS
  by
  DIATHERMY

MECHANICAL METHODS
  by
  ELECTROLYSIS

such as

CHEMICAL METHODS
  using
  CREAMS
  which loosen hair roots

CUTTING
  using
  SCISSORS
  SHAVING

PULLING OUT
  using
  TWEEZERS
  WAX
  SUGAR

for eyebrows
for legs
for legs
Sabrina's 2nd concept map on the physics and chemistry of depilation incorporating extended knowledge of electrochemical methods.
Cathy's 1st concept map on 'Introduction to the physics and chemistry of depilation.'

**Superfluous Hair**

- Can be removed by:
  - **Mechanical Methods**
    - Using:
      - Wax
      - Sugar
      - Pulls out the whole hair
  - **Electricity**
    - By:
      - Electrolysis
      - Electricity makes a chemical which dissolves the hair root
  - **Chemicals**
    - In:
      - Creams
      - These dissolve the root of the hair
Cathy's 2nd concept map on 'Introduction to physics and chemistry of depilation incorporating extended knowledge on electrochemical methods.'

Superfluous hair can be removed by electricity using diathermy where electricity makes a needle hot inside a hair follicle and this kills the root so the hair can be pulled out easily.

Electrolysis where a small current of electricity in a probe will make a chemical called sodium hydroxide which kills the hair root so the hair can be pulled out easily.
Example of material used in teaching a basic understanding of atomic structure.
13) Give the full electronic arrangement in the following dot and cross diagrams. (The first three have been done for you).

Top Tips: You might not see the point of all this yet (you soon will, don't worry), but in Exams they're always asking you to draw out electronic arrangements, or "configurations" as they sometimes call them — just make sure you can work them out from atomic numbers or the Periodic Table. Sometimes they only ask for the outer shell to be drawn — easy or what......


Association for Science Education (1979) Alternatives for Science Education. London: Association for Science Education


Barker, V. (2000a) Beyond Appearance: Students' misconceptions about basic chemical ideas. London: Royal Society of Chemistry.


Kinchin, I.M. (2000b) If concept mapping is so darned good, why aren't we all doing it. Unpublished Research Seminar, University of Surrey.


Lawson, K. H. 1998 Philosophical Issues in the Education of Adults Nottingham: Continuing Education Press, University of Nottingham


Reich, E. S. (2009) Don't be so sure that our universe is flat. New Scientist 16 May 2009


Ross, K. (1993) There is no energy in food and fuels - but they do have a fuel value. School Science Review 75, 221, 39-47.


Science Education 21, 12, 1223-1235.

misconceptions. Reports from the Institute of Education, University of Gothenberg,
76.

Salomon, G. & Globerson, T. (1987) Skill may not be enough: The role of
mindfulness in learning and transfer. International Journal of Education Research
11, 6, 623-637.

Schauble, L. (1996) The development of scientific reasoning in knowledge-rich
contexts. Development Psychology 32, 1, 102-119.


Schwandt, T.A. (1998) Constructivist, interpretivist approaches to human inquiry in
Denzin, N.K. & Lincoln, Y.S. (eds) The Landscape of Qualitative Research: Theories

Science Master's Association (1957) Science and Education, in School Science
Review Nov. 1957. London: Association for Science Education

CEE/University of Bath.

Routledge


Skirtic, T., Guba, E. G., & Knowlton, H. E. (1985) Special education in rural
America: Interorganizational special education programming in rural areas (Technical
report on the multisite naturalistic field study). Washington D.C.: Dept. of Education,
National Institute of Education


Suppes, P. & Ginsberg, R. (1963) A fundamental property of all-or-non models, binomial distribution of responses prior to conditioning, with application to concept formation in children. Psychological Review 70, 139-161.


Watson, J. B. (1913) Psychology as the behaviourist views it. Psychological Review 20, p158-177


Whelan, R. (2009) From Two Cultures to No Culture: C.P. Snow's "Two Cultures" lecture 50 years on. London: Civitas


