Science and Mathematics Education Centre

ANALOGIES CONSTRUCTED BY STUDENTS IN A SELECTIVE HIGH SCHOOL

Julianne Kathleen Crowley

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DEDICATION

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ABSTRACT

Research in science education over the past 20 years has emphasized the importance of active cognition in conceptual development. Students formulate knowledge within language constructions constrained by culture and social construction and relate to their own purposes using speech and writing. Many students in high school do not recognize the use of analogy in the development of science theory and concepts. By focusing on the constructed nature of science and analogy this thesis aimed to determine the capacity of high ability students to engage their own thinking and so have a powerful tool with which to deconstruct and reconstruct their scientific understandings.

This thesis focused on the use of analogy in a Year 7 electricity unit and a Year 9 geology unit and used examination questions, quizzes, diary entries and interviews to determine the role of analogies in learning. The specific research questions asked were: Can high ability students create their own analogies?, What role do analogies play in learning?, and How do analogies help students in concept development?

The thesis found that analogies are powerful tools in supporting student conceptual development. They allow students to link from their existing framework to new understandings and visual analogs were the most effective in supporting learning. The students move to new understandings may not happen within the teaching time but could occur several months after the introduction of the analogy.

High ability students are able to recognize and construct their own analogies; however, many students have difficulty deconstructing analogies on their own. The content of the student created analogies seemed to be associated with activities involving reflection and reflection time emerged as a critical component of the learning process. The role of analogies in providing a focus for discussion with peers, teachers and parents so that ideas could be thought about, tested and clarified was found to be one of their important functions in supporting learning.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

THE ROAD NOT TAKEN

Two roads diverged in a yellow wood,
And sorry I could not travel both
And be one traveller, long I stood
And looked down one as far I could
To where it bent in the undergrowth;

Then took the other, as just as fair,
And having perhaps the better claim
Because it was grassy and wanted wear,
Though as for that the passing there
Had worn them really about the same,

And both that morning equally lay
In leaves no step had trodden black.
Oh, I marked the first for another day!
Yet knowing how way leads on to way
I doubted if I should ever come back.

I shall be telling this with a sigh
Somewhere ages and ages hence:
Two roads diverged in the wood, and I,
I took the road less travelled by,
And that has made all the difference.

By Robert Frost (Cherry, 1966, p. 113)

This poem by Robert Frost speaks of life as a journey, a journey we all travel as we move through life, making decisions and choices because of who we are, about challenges and experiences we confront. These choices in turn determine future choices and mould the individual we become.

OVERVIEW

This chapter describes the journey I took as I engaged in the research for this thesis. It describes, in part, the beginning of this journey but focuses more on the challenges that emerged as I grappled with the realities of the role and expectations of Head Teacher of Science at a selective boys high school in Sydney as well as coping with the demands of doctoral research. These challenges included the creation of a gifted and talented class, the choice of a thesis topic and the threads followed with the subsequent case studies. The thesis is informed by constructivism, which also underpins the research questions investigated. The chapter concludes with a brief outline of the structure of the report.

A Personal Journey

This thesis, in part, describes reflections on a journey and is directly drawn from several years of teaching in a boys' high school with selected academic entry in the inner suburbs of Sydney over the period 1996 to 1998 and my enrolment as a doctoral student at the National Key Centre for School Science and Mathematics at Curtin University of Technology.

A Master's Degree in Education in 1982, awarded by the University of Sydney, was behaviourist in emphasis although Piagetian ideas were included. Some years later, in a position as Lecturer in Science Education at Kuring-gai College of Advanced Education, now part of the University of Technology, Sydney, I was interviewed as part of a review of science education in Australia by Fensham, Corrigan and Malcolm for the Curriculum Development Centre, Canberra. This interview essentially challenged the understandings which underpinned my preservice teacher development, as it became apparent that a new paradigm was emerging. Institutions that had not moved to adopt it were likely to be dismantled and reconstructed.

In the early 1990's, I enrolled as a part-time, distance education doctoral student through Curtin University of Technology and completed several course-work units. From previous university experience while completing a science project on endosulfan, an organochlorine pesticide used extensively in agriculture, titled *Endosulfan impaction in agriculturally impacted soil* (Crowley, 1988), I was aware of the problems of completing projects not immersed in the workplace and so wherever possible I endeavored to focus on the coursework assignment requirements for the doctoral program in the school or classroom where I was working. This had the added advantage of allowing me to re-evaluate my classroom teaching within the developing paradigm of constructivism.

Identification of a thesis topic changed several times as my workplace changed from university to an all girls' secondary school, and eventually in 1994 to a selective government all boys secondary school, North Sydney Boys' High School (NSBHS). I then started looking for a topic within this setting, keeping to my original need to embed the research within my workplace.

Initial Experiences at a New School

In 1995, science classes at NSBHS were streamed and my first experience of this new setting was with a Year 9 lower stream science class. I had high expectations of students at the new school because entry was via a testing series of examinations but I was rudely jolted out of these perceptions. These students appeared to have lost their interest in science, expecting their science class to be a continuation of the social life of the playground. They had been identified as failures and rather than fighting against this label, most behaved in a manner and produced work of a standard which reinforced this belief.

Also included in my allocation were students in a Year 7 class who were excited and, as most Year 7 students are, enthused with the challenge of high school. In Year 7, everything about high school science is new so students accept as normal high school science class requirements, portfolio development, assignments looking at the relevance of science, and metacognitive exercises. I tried introducing similar assessment procedures to the Year 9 class but compared to the Year 7 students, the Year 9 work was below the quantity and quality of the Year 7 work. It became clear that unless students have been introduced to alternative assessment strategies early, they have an established view of how science education should be conducted. Even though the Year 9 group had failed traditional, existing assessment procedures, as academic achievers they have a vested interest in maintaining the established and familiar system of assessment. One way around this was to create a changed perception by avoiding the labelling of science students as failures at the end of Year 8 and by not reporting on students in classes, that is, ranked out of a class of 30. Previous reporting had ranked students in a year group, that is as a position out of 150; no school student needs to be ranked 150/150.

Creating an Environment which Allowed Changed Student Perceptions

In 1996, as Head of the Science Faculty at NSBHS, I abolished streaming of science classes and created randomly assigned classes. It was apparent that in a selective high school, students were underachieving, not because they were unable to cope with the material but because as adolescents other things were more important at that time of their lives. This view had been reinforced in my first year when lower stream students moved from the lowest quartile of the year to the highest in one semester due to increased parental interest. Further, my view has since been confirmed by a visiting speaker from the selective high schools unit who indicated at a seminar on 30 April, 2001 that the bottom cut off for entry to NSBHS corresponded to an intelligence quotient, IQ, of about 130 (Gifted Education Research Resource and Information Centre, 2001). Other factors impinge on students at this time: for boys, Year 9 is often a more obvious time of change than for girls as they cope with a huge changes in their perception of self, peers and in the community. These changes can involve adding several centimetres to their height, voice changes and hormonal variability as they move through adolescence. If cross-cultural expectations are included, another dimension of life issues is added. Indeed, over 50% of NSBHS students do not speak English at home (Newsom, 2001), supporting the assertion that cultural issues are a factor in many students' lives at this time.

In 1996, to assist the acceptance of alternative assessment strategies across Year 9, both by Year 9 and by established teachers, and to use classes above Year 7 as part of my doctoral research, a special Year 9 class was established, 9S1; other Year 9 classes remained ungraded.

Entry to 9S1 was by application by students or parental recommendation during the fourth term of Year 8. Students were advised that students in 9S1 would be required to complete the normal sequence of units but that the science itself would be extended and the assignment schedule would be different. The main criterion for entry was an interest and involvement in science rather than high marks in Year 8. On receipt of application forms, a list was made of all students, their involvement in science was ranked and, where there were difficulties, the students' applications were discussed with their Year 8 teacher as to their perceived interest in science over the past year. From these applicants, a class of 30 students was created. This class was a high ability, motivated group of students. The same process was repeated in 1997 and 1998.

THE ORGANISATION OF THE RESEARCH PROJECT

Survey Results at the End of the First Unit

The creation of 9S1 was a new initiative, and I was still coming to terms with students in a selective context, and being uncertain of the pre-existing knowledge levels of the newly-created group, the pace of teaching and type of delivery. Consequently, a survey was administered at the completion of the first unit of the year. On first reading of the survey forms, the researcher was overwhelmed by the perception of negativity to the material and these forms were put aside for several weeks. Later the forms were coded and the responses examined in more detail.

It became quickly apparent that my initial reaction was invalid; most students responded positively to the survey. The negative responses came from a group of three or four students only and when the survey was coded and totalled, only four students felt the class was boring and not up to their expectations. Twenty-two students found the class work interesting and half the respondents referred to the practical nature of the class and believed they were learning with understanding. Most students found the teaching level just right, and only three found it too easy. What was informative to me was that eight students reported that the unit had no relationship to life outside the classroom; this was surprising because the unit had been deliberately planned to overtly relate the material about chemical compounds to the students' life outside the classroom. For a while, I took this as a failure on my part to convey this to the students, but on reflection this could be seen as the result of the compartmentalization of students' knowledge. On review, I decided that what was initially perceived to be a failure would instead be the starting point of this doctoral thesis because an underlying assumption of science teaching is that it links to, and develops for students a current western conceptual understanding of the world outside the classroom. The information and concepts presented are those that are an intimate part of students' experiences. That a large number of Year 9 students did not see their school science course in this light reflects perhaps a failure of the units presented or a separation of school and life.

Year 9 Analogies Assignment

Analogies are agreements, likenesses or correspondences between the relations of things to one another (Delbridge et al., 1991). Replicas and scale models are familiar examples of scientific models (Hesse, 1967) used to more clearly explain theories or concepts. Scientific models can be theories to explain observations or they can be a picture intended to explain a theory more lucidly (Lacey, 1996). The relationship between model and the thing being modelled can be an analogy. Simplistically, science analogies are a special group of scientific models. This is discussed more in Chapter 2.

Writings by Duit (1991) and Treagust (1995; 1996) on analogies and their strength in linking the students' experiences with science concepts, and the development by the author of a Year 7 Unit on Electricity informed by constructivist notions of learning based on the work of Cosgrove and Osborne (1983) and Cosgrove (1995), encouraged me to develop assessments which would investigate high ability students' understanding of analogies. Students were to identify and deconstruct analogies from a current unit of work and then create their own analogies and deconstruct them. This assessment was an assignment in the Year 9 geology unit, The Active Earth, as the literature reviewed revealed little had been written on analogies in geology for high school. This assignment was the second piece of data collected for this thesis.

Year 7 Electricity Examination

Electricity was a unit that challenged students' conceptual understanding. It presented four different models to explain the movement of electrons/electricity in a simple electric circuit. Students voted on the model that they believed best explained the flow of electricity and no student voted for the scientifically accepted view. The four models were tested in an experimental situation by placing two ammeters in a simple circuit and recording the results. Only the scientifically accepted view of electric current can explain the result where the ammeter between the battery and the bulb and the ammeter between the bulb and the battery both record the same number of amps in an open circuit. As a result, Year 7 students developed an analogy for electrical current to overcome the conceptual dilemma created. At the completion of the unit all students voted on the four models of electricity again and all students voted to accept the scientific model taught during the unit.

I prepared the electricity questions for the yearly examination and marked the answers. While not initially planning to use this work to support the work on analogies, on marking the electricity component it became apparent that several students had reverted to an alternative view of electrical understanding and this work could be used as a measure of analogue retention and longevity. The examination scripts became the third piece of data to be coded and included in this thesis.

Year 8 Review

From the Year 7 examination scripts, it was apparent that several students had altered the analogy developed in class and reverted to an alternative model to explain the movement of electricity in a simple circuit. The examination was held about six weeks after the completion of the classroom instruction and I then asked how many more students would alter their conception if students were reassessed several months later? Subsequently, the Year 7 Electricity component of the Year 7 examination was administered to the same group of students five months later, when they were in Year 8. The results were compared with those obtained in Year 7. These data, which would add to the information obtained in the Year 7 Examination scripts on analogue retention and longevity were transcribed and coded to become the fourth piece of data collected.

Year 9 Diaries, 1997

In 1997, I decided to look more closely at Year 9 students' awareness of analogies in other units in science by the use of diaries. Diaries were started but due to classroom pressures of time only ran for three lessons. Nevertheless, these incomplete diaries were coded and used to respond to the research questions. These diaries became the fifth piece of data collected for this thesis.

Year 9 Analogies Assignment, 1997, 1998

Giving the assignment to two more 9S1 cohorts increased the validity of the assignment work completed in 1996. These assignments became the sixth and seventh pieces of data to be coded and used to investigate the ability of high ability students to identify, create and analyse analogies.

Year 9 Interviews

Several students from the Year 7 class were interviewed when they were in Year 9 to provide additional insights to the Research Question: How long do analogies created in the classroom remain with high ability students? These interviews became the eighth piece of data for this thesis.

Year 11 Interviews

While reviewing the project in 1999, the researcher became aware that added insights relating to the Research Question: How do analogies help students in concept development? would be gained from speaking in depth to several students from the specially created Year 9 class. These interviews became the ninth and final piece of data in this project.

THEORETICAL FRAMEWORK

Constructivism is a theory about how learners acquire knowledge. It describes the way people attain and develop their ideas, or use their cognitive processes to acquire functional concepts of the world around them. Within this philosophy of knowing, the development of ideas and concepts is seen as an ongoing process throughout life. Constructivism is not a new theory but rather the refinement of a series of beliefs that have been around since the eighteenth century (von Glasersfeld, 1989). Constructivism is an active process involving mental processes, experiences with the environment and social interactions. In order to construct their view of the world, learners need to have varied meaningful experiences and develop the models and principles of conventional science. The challenge, according to Driver (1989), is for science educators to assist learners to construct these models. How this framework informs and supports this thesis is discussed in detail in Chapter 2.

RESEARCH QUESTIONS

1. Can high ability students create their own analogies? Within this question are the sub-set of questions:
   - 1a What type of analogy do students create?
   - 1b Can students deconstruct their own analogies?

2. What role do analogies play in learning? Subsumed in this question are three sub-questions:
   - 2a What type of analogies are the most effective for supporting conceptual change in students?
   - 2b How long do analogies created in the classroom remain with high ability students?
   - 2c If students revert to alternative analogies what happens to the original classroom analogy?

3. How do analogies help students in concept development?

The premises upon which these research questions are based include the notion that learning is an active process and that students are not intuitively aware of the structured nature of the language of science. When made aware of the constructed nature of science, students are able to identify analogies in a science text. Analogies are an integral part of the language of science in that analogies allow students to link new information with familiar concepts. During the internalisation of concepts, analogies allow students to function and solve problems in new situations.

SIGNIFICANCE OF THE STUDY

The teaching of science is based on current theories of scientists' descriptions and interpretation of the theories underpinned by observations. These theories have been developed over the course of civilization but have gained a greater prominence since the Middle Ages. Dalton, Lavoisier, Avagadro, and Moseley are just a few of the chemists who have added to our current theories concerning the behaviour of matter. Their theories are a series of analogous explanations that make our interaction with the observable world understandable.

The role of analogies in developing scientific theories has been written about extensively from different perspectives and analogies have helped in the discovery, development and evaluation of scientific theories over the past two thousand years. For example, the analogy between sound and water waves was used by Vitruvius to explain the acoustic properties of Greek amphitheatres in the first century A.D. In 1660, William Gilbert described the Earth as like a large magnet and later Isaac Newton used analogy to support his hypothesis that gravitational forces govern the orbits of planets. By comparing the planet to a stone thrown upwards from the Earth with ever increasing force, Newton concluded that with enough force the stone would assume the path of an orbit around the earth. During the 1770's, Lavoisier developed his theory about the role of oxygen in animal respiration, his work being guided by an analogy between respiration and combustion. In 1915, Morgan described genes as being like beads on a string. Current computational theories have been linked to the working of the mind (Holyoak & Thagard, 1995).

Analogies also have been important in the teaching of science. Goswami (1992) believed that reasoning by analogy is central to human cognition. She argued that analogy is involved in classification and learning providing a tool for thought and explanation as well as a vehicle for creativity.

This research is embedded in a classroom in a selective high school and looks at the use of analogies in a normal learning situation. Most of the literature dealing with classroom-based science education is based in the comprehensive classroom, and any literature dealing with high ability students is usually embedded in the primary school classroom.

Research dealing with high ability students comes under the umbrella of Gifted and Talented (GAT) and is usually directed at very high ability students. Very little research has taken place in the selective school classroom and in today's political climate, research in this area is not funded as it is seen to be in competition with the comprehensive system, in a period when enrolments in New South Wales state schools are falling while enrolments in the non-government education sector are increasing (Australian Bureau of Statistics, 2000).

Few teachers in New South Wales have had any training in the education of high ability students and this background is not considered when appointing teaching staff to selective high schools. In some areas, the selective school is a place to locate staff who have had difficulties in other situations. In many selective high schools, there is a belief that the school has no need to develop new strategies or support investigation of alternative teaching strategies, as the schools' results in external examinations are already excellent.

Results of this research should enhance students', teachers' and researchers' understanding of the way high ability students learn in a classroom setting as it has the potential to increase students' engagement and enhance the teaching of science. In turn, this research should promote student understanding, an objective of all science teachers. Unfortunately science instruction frequently is not designed for the science perspective to be learned efficiently (Duit & Treagust, 1998), a sad situation that has resulted in science instruction having very often limited success (Hewson, 1996b). and this presents a major challenge to science teachers. Any research relevant to the classroom that supports students' conceptual change is important and investigating the use of analogy in science learning is one way of achieving this goal. By exploring students' ability to identify, construct and critically analyse analogies, considerable progress can be made in understanding the process of conceptual change within the classroom setting (Treagust, Duit, & Fraser, 1996). This information will assist teachers in supporting and enhancing student learning.

STRUCTURE OF THE REPORT

This report is divided into six chapters.

Chapter 1: Introduction and Overview

Chapter 1 briefly describes the genesis of this thesis and the educational background, the teaching experience of the researcher and outlines the stages in the collection of data. The background and organisation of the research study are presented, the research questions outlined and the significance of the study presented. The purpose of the overview is to describe the structure of the thesis and enhance the readability and cohesion of the final document.

Chapter 2: Literature Review

Chapter 2 is the literature review. Firstly, the chapter examines a definition of conceptual change and traces the background of this term in the literature. The second topic discussed is the literature associated with analogies and their function in supporting conceptual change. Finally, a description of the gifted and talented learner in Australian schools is presented.

Chapter 3: Theoretical Framework and Methodology

Chapter 3 outlines the research approach taken in this thesis that was carried out within the constructivist paradigm. The approach taken was that the theory would be grounded in the data.

The research strategy described in Chapter 3 is of multiple linked case studies. A total of nine sets of data were collected within two classroom frameworks. Six of these cases are used for the analysis of the students' ability to identify, create and deconstruct analogies in a classroom setting; one of these takes a closer look at the effectiveness of analogies in supporting conceptual change. Three of the cases examine the longevity of analogies, which underpin conceptual change, and one of these takes a closer look at longevity and the effectiveness of analogies in sustaining conceptual change in electricity.

Traditional notions of research rigor such as internal validity, reliability and objectivity were side-stepped for different standards that suit naturalistic or constructivist inquiry. Credibility, transferability, dependability and conformability are enhanced through triangulation of the data sources. In addition, the researcher presents a methodology and case studies with a "thick description" (Guba, 1981, p.119) that allows readers to come to their own conclusions with the researcher.

The ethical approach guiding this thesis is outlined in this chapter. The list of processes includes a code of exchange of information, a code of confidentiality and a code of trustworthiness that the researcher adhered to throughout the research process.

Chapters 4 and 5: Results and Discussion

The results and discussion are presented as two chapters. Chapter 4 presents data from the Year 9 classroom confirming the assumption that students are not intuitively aware of the constructed nature of science and so do not recognise analogy in science until it is made overt. The development of Research Question 1: Can high ability students create their own analogies? as well as the subsumed sub-questions, What type of analogy do students create? and Can students deconstruct their own analogies? are answered in Chapter 4. The chapter also presents interviews with several Year 9 students when they were in Year 11. A phenomenographic analysis was conducted on the data, firstly by coding fully and then by seeking to categorise the responses into qualitatively different groupings based solely on the data to provide evidence to answer the questions posed.

Chapter 5 presents data from the Year 7 classroom and interviews with the Year 7 students when they were in Year 9. This chapter focuses on the Research Question 2: What role do analogies play in learning? and the subsumed sub-questions: What type of analogies are the most effective for supporting conceptual change in students?, How long do analogies created in the classroom remain with high ability students?, and If students revert to alternative analogies what happens to the original classroom analogy? The Year 7 examination results and the Year 8 review were coded and categorised using a phenomenological framework to provide evidence to allow the researcher to answer these questions.

Chapter 6: Conclusions and Implications

The final chapter summarises the conclusions of this thesis by addressing the research questions outlined in the first chapter. Research Question 1 is answered by examining the results presented in Chapter four and Research Question 2 by examining the results obtained in Chapter five. Research Question 3 is also answered in this chapter by considering two interviews with the same students over a period of two years.

Finally, further possibilities for research in this area are discussed including: the use of special classes; development of diaries and their role in monitoring the analysis of analogies; conceptual change over a longer time frame; as well as providing a framework for the meta-analysis of learning by high ability students.

CONCLUSION

This chapter introduces this study and presents an overview of the subsequent chapters and is intended to provide a sequence which can be followed throughout this thesis.

CHAPTER 2

LITERATURE REVIEW

As an infant, I learned that there was a 'me' and a 'not-me'. I began to know that my hunger was me, and the source of satisfaction was not-me. I experienced this difference before I learned language, before I could think in words and sentences. In this way, my knowing process began to develop.

(Daniels & Horowitz, 1976, p. 223)

INTRODUCTION

The science education literature revealed how the presentation, and information taught, related to each in the development of student understanding. As I developed understanding, I was able to use that information, and not just know it.

This thesis examines learning in science, in part by looking at the ability of students to use and interpret analogies in science and more generally by seeing how this knowledge can inform educators about the learning of high ability students. The background reading involved the researcher's conceptual change as she interpreted the literature. The thesis reflects a journey from a teacher's view of science embedded in a behaviourist, positivist philosophy towards a post-modern view which sees science as a human construction changing over time.

This chapter reviews the educational ideas that guided and informed my personal evolution and the consequent interpretation of the data. The chapter specifically reviews the literature on constructivism, analogies and high ability students. , The researcher now views, through the philosophy of learning known as constructivism, the learning environment and the constructed nature of science in which I am immersed.

BACKGROUND OF THE RESEARCH FRAMEWORK

Prior to a discussion of the literature associated with the thinking of constructivism it is important to reflect briefly on where this philosophy came from and why it underpins this thesis.

Positivism

Positivism, a way of viewing the world that has dominated science and the social sciences for over 400 years (Guba & Lincoln, 1994), is a philosophy that asserts that sense perceptions are the only admissible basis of human knowledge and that knowledge of the world can only be gained by experimentation. It is a way of knowing which demands objectivity and is based on the assumption that there exists an objective reality that operates, according to immutable laws, outside of us. According to Cohen, Manion and Morrison (2000), positivism is historically associated with the French philosopher Auguste Compte who first used the word for a philosophical position. Since Compte, the term positivism has been used by philosophers and social scientists in such a variety of ways that to give it a precise and consistent meaning is impossible (Cohen et al., 2000). Positivism has been applied to the school of philosophy known as logical positivism which arose out of the destruction of Europe, physically and socially, at the end of World War II and the formation of the Vienna Circle in 1926 (Galison, 1996). The views of logical positivism enunciated by the Vienna Circle are stated in its manifesto, the preface to Wissenschaftliche Weltauffassung: Der Weiner Kreis [Scientific World View: The Vienna Circle] drafted by several of this group in 1929:

> [logical positivism] is the spirit of the scientific world–conception penetrating in growing measure the forms of personal and public life, in education, upbringing, architecture, and the shaping of economic and social life according to rational principles. (Carnap, Hahn, & Neurath, 1929, p.vii.)

The term positivism, however, has a meaning derived from its use in natural science as the paradigm of human knowledge. Positivism here implies the stance taken by the social scientist as an observer of social reality. This means that research must be an experimental or quasi-experimental validation of theory using quantitative analysis, for example, using mathematical models, and the results of this analysis must be expressed in laws (Cohen et al., 2000).

Postpositivism

Postpositivism represents efforts to reply to the criticisms of positivism while still remaining essentially within the same set of beliefs. Postpositivists argue that reality exists but can never be appreciated, or that reality can only be approximated because of an individual's limited intellectual ability. In order to capture as much reality as possible, postpositivists use multiple methods to support their research to make it as rigorous as the work of the quantitative researchers by the discovery and verification of theory. Evaluation criteria such as internal and external validity are employed as are the use of qualitative data that lend themselves to structured, often statistical, analysis (Denzin & Lincoln, 2000). Positive and postpositive philosophies both are two separate entities and not opposites of each other.

The positivist and postpositivist traditions, according to Denzen and Lincoln (2000), linger as long shadows over qualitative research as qualitative methods emerged from within the positivist and postpositivist paradigms while researchers tried to carry out research using less rigorous methods and procedures. Although some qualitative researchers believe that there is some validity in the use of these two traditions as yet another way of telling stories about the world, there are others who believe that too many voices are unheard within these traditions and thus do not share this view (Cohen et al., 2000).

Behaviourism

According to Graham (2000), behaviourism is the science of behaviour not a science of the mind. Behaviourism is a theory which maintains that on one hand immaterial minds do not exist and on the other that mental events (whether an immaterial mind exists or not) cannot be seen as independent from the overt physical behaviours of an organism. There may be mental states but behaviourists explain everything without reference to them. According to von Glasersfeld (1995), behaviourism is a model of learning derived from animal observations. In an oversimplification, he describes the underpinning of behaviourism as being "derived from experiments with captive pigeons and rats" (von Glasersfeld, 1995, p. 4). Animals repeat actions that lead to expected outcomes and in this way behaviour is reinforced. Behaviourism became a learning theory based on the power of observation; however, the problem with behaviourism as a learning theory is that it focused on results rather on the reasons why people respond or act in a certain way. There is no focus on the learner's understanding of a problem and this leads to comprehension by chance.

Behaviourism is subdivided into three schools: methodological behaviourism, psychological behaviourism and analytical behaviourism. Methodological behaviourism claims that psychology should concern itself with the behaviour of organisms, be they human or otherwise, and there should be no reference to the mental state of the organism. Psychological behaviourism believes that intelligent behaviour is the product of associative behaviour while analytical behaviourism is a theory about the meaning or semantics of mental terms or concepts. All these schools have their historic roots in positivism or logical positivism. According to Graham (2000), one of the goals of positivism is the unification of psychology with the natural sciences.

Critical Theory

Guba and Lincoln (1994) describe critical theory as a blanket term grouping several philosophical frameworks, including neo-Marxism, feminism, materialism and participatory inquiry. Further, they sub-divide critical theory into three sub-strands, namely, post-structuralism, post-modernism and a blending of the two in which the real world makes a difference in terms of race, class and gender. Post-structural theories emphasise problems with the social environment, that is, it is impossible to represent the world of experience fully in an historical realism; rather it is a reality shaped by social, political, cultural, economic, ethnic and gender values. The findings of research from these philosophies are subjective and value-mediated and what counts as knowledge is defined by power (Denzin & Lincoln, 1994). Indeed, power and knowledge become synonymous within these frameworks and theoretical arguments are evaluated in terms of their emancipatory implications to expose the hidden power-knowledge structures without erecting new ones (Denzin & Lincoln, 2000).

Constructivism

Constructivism is embedded in the post-modern view of reality in which, according to Polkinghorne (1992), human experience is a construction and the meaning of events and objects is generated by cognitive recognition of each as a mental pattern or scheme. During the 1960's and 1970's, there was a philosophical shift from behaviourism to various forms of structuralism and cognitivism, which in turn led to a rethinking of psychology, sociology, linguistics and anthropology and the renewed interest in concept formation, problem solving and the link between cognitive structures and behaviour. One form of cognitivism became known as constructivism. Within this framework, constructivism holds that all knowledge is constructed and that the cogitative structures which allow this are innate or are themselves the product of developmental construction (Noddings, 1990).

Von Glasersfeld (1989) describes constructivism as a theory about knowing and explains how people develop ideas, or schemes, of the world around them by incorporating mental processes, the environment and social interactions. Within this philosophy of knowing, the development of ideas and concepts is seen as an ongoing process; multiple realities and understanding of these realities are determined jointly by the researcher and researched. Methodologies in this paradigm are set within a naturalistic setting. Guba and Lincoln (1989) named their philosophical view of research as being constructivist, in place of their previous description as naturalistic research. They saw the meaningful construction of individuals and groups as the only reality that could be studied, believing that there was no reality except that which people construct as they make sense of the world around them.

Constructivists believe that subjective and intersubjective social knowledge and the active construction and co-creation of this knowledge by people is a product of human consciousness (Denzin & Lincoln, 2000). This belief is not new and Gash (1983) presents an early eighteenth century treatise by Giambattista Vico which questioned the concept of knowledge as an objective reality. Vico developed the idea that knowledge was constructed in the mind of each individual.

Piaget

Piaget set the modern groundwork for the constructivist way of knowing with his stages of intellectual growth of children. Piaget was concerned with the way children construct knowledge and he recognised the self-regulation process in individual learning. Piaget provided an essential key to children's conceptions when he demonstrated that a child may see a scientific idea in quite a different way to that viewed by an adult.

In one of his experiments described in *Time* (Papert, 1999, p. 104), Piaget asked children "What makes the wind"? A typical child response was "The trees" because "I saw them waving their arms". When further asked " How does that make the wind?" Julia, one of the children, waved her hand in front of the interviewer's face and said "Like this. Only they are bigger. And there are lots of trees".

Piaget recognised that five-year-old Julia's beliefs, while not correct by adult criteria, are not incorrect either, the differences not being due to lack of technique or information. Children's ideas are built from different experiences and cannot be replaced by simple provision of the correct idea. Before a child will change his or her idea, he or she must be persuaded that the existing ideas are no longer effective or that an alternative view is preferable (Confrey, 1990). Constructivism for Piaget arose out of dissatisfaction with the traditional theories of knowledge where knowledge of a real world that is thought of as existing separate and independent of the knower; this knowledge should only be considered true if it correctly reflects that independent world.

Today, two major schools of thought about constructivism have developed – radical constructivism and social constructionist. The thinking behind each of these schools of thought is discussed in the next sections.

Radical Constructivism

Von Glasersfeld (1995) describes a skit by the comedian Mark Russell to highlight the philosophical tensions that confront education today. Russell talks about the perceived decline in education over the past 20 or 30 years and describes how children leave school unable to read, write, or manipulate numbers well and have so little science knowledge that they believe that the phases of the moon are caused by the earth's shadow. Russell states "Give the teachers more money and they will teach the right answers" (von Glasersfeld, 1995, p. 4). Von Glasersfeld believes that a philosophy of education, which believes in teaching the right answers, is not an education worth having.

Von Glasersfeld (1995, p. 21) is very negative about an educational system where children are taught the right answers, as he believes that learners construct their own knowledge using existing knowledge and therefore view the world in ways that are coherent and useful to them. The idea of being taught the right answer he believes is due to the ascendancy of the philosophy of behaviourism, where the concepts of teaching and training became confused.

Research at the University of Massachusetts has shown that first year physics students are able to solve standard problems but when asked to solve simple problems that are different from the standard format they lacked the understanding of the conceptual relationships which underpin the formulas they have learned by rote. Solving pages of similar problems does not lead a learner to automatically acquire conceptual understanding. The learner needs to acquire an understanding of all the relationships, and acquire a conceptual repertoire in order to solve novel problems. Von Glasersfeld (1995, p.5) states that "concepts cannot be simply transferred from teachers to students – they have to be conceived".

Von Glasersfeld then describes how conceptual development needs to be fostered and developed into an epistemology of learning that incorporates an understanding of the learner's construction of understanding. This is the epistemology of constructivism that questions the traditional concept of knowing, which assumes that in knowing the learner gains an understanding of an independent reality. Within constructivism, knowledge represents "what we can do in our experiential world" (von Glasersfeld, 1995, p. 7). Constructivists believe that knowledge of an independent world is impossible or that meaning can only exist within a learner's own experience. Because of their experiences, learners believe reality to exist, and that others rely on their version of reality too.

Knowledge is constructed as a compendium of actions and beliefs that an individual has found to be successful in certain situations. According to von Glasersfeld (1995), this is analogous to the notion of adaptation in evolutionary biology, expanded to include the goal of survival. Knowledge within the constructivist framework becomes the ability to conceptualise the world as the individual knows it in order to survive. It is a function of the viability and of the individual being able to create as coherent a conception of their experimental world as possible.

The notion that knowledge is viable negates the need for an objective truth. This notion is explained with reference to the southern hemisphere constellation, the Southern Cross. This constellation is familiar to all in the southern hemisphere and forms part of the symbolism of the Australian flag. Its shape has been recognised by sailors for thousands of years and it has served as a navigation aid. The Southern Cross has not changed in the human memory and is as real as any visual object can be. However, if individuals moved in their position in space from Earth to another point in the universe, this object would no longer exist. Where does the Southern Cross exist? Constructivists claim that it is a construction in our minds and depends on the action of picking a particular group of stars to create a connection that individuals think is appropriate. It is part of an individual's subjective construction of their experiential world.

Beniot Mandelbrot (1982) posed a question, which seemed obvious, when he asked the length of the British coastline? It seemed a simple question, which, if not already known, required simple measurement. But measuring it posed a difficulty. If carried out by triangulation, what would be the distances between points and where would points be located? If the distance was to be measured with a rule, at which point should the measurements be taken, at high tide or low tide mark? Other problems included things like whether the distance around sand bars was to be included in the final measurement? Depending on where and how the distance was measured, the result would be different and this raised the question of whether the British coastline existed? If the conceptual constructs created are removed, then the notion of coastline ceases to exist. This supports the notion of a shared constructed reality according to philosophers such as von Glasersfeld (1995).

To further support the concept of the constructed nature of knowledge, von Glasersfeld (1995) described the concept of an equilateral triangle where students in a geometry class had no difficulty in understanding what was being talked about and when asked to draw an equilateral triangle all students could construct one. Theoretically, an equilateral triangle should be constructed as three continuous lines so in actuality no student was able to draw an equilateral triangle. Precise measurement would show that the lines were not exactly equal and magnification would show that the lines were merely a succession of marks, not straight and definitely not equal. The class knew what was being discussed, yet it exists only in their minds. The constructs here were an agreed upon set of relationships which the group understood.

Plurality, according to Piaget and discussed by von Glasersfeld (1995), is a mental construct, not a sensory construct, that builds on the use of recognition procedures taking place over and over again in different places. Plurality must be constructed and so it cannot be taught; knowledge is learned as part of the social interactions that govern our knowledge of reality. These understandings are created by each individual's experiences and gain legitimacy in a social context. Learning is not a stimulus-response process, but is the building of conceptual structures through reflection and abstraction. To solve a particular problem one has to see it as personal, as an obstacle that obstructs the individual's movement towards a goal. The desire to solve a particular problem is how much an individual sees it as his or her problem and that translates as motivation. The individual's satisfaction is gained not from getting the problem right, but in solving it. Within the constructivist epistemology, the teacher must be able to interpret what the student does and try and build up a model of the student's conceptual structures. Unless a teacher can elicit an explanation of how the student has arrived at an answer, the chances of modifying the student's conceptual structures are minimal.

Social Constructivism

Social constructivism identifies two perspectives on the sources of knowledge, an exogenic or world-centered view, and endogenic or mind-centered view (Gergen, 1995). In the exogenic view, the external world is set against a psychological world, where the emphasis is on keen observation in the acquisition of knowledge. The student is seen as having a *tabula rasa* upon which the world is inscribed; the mind is able to work best when it can directly reflect the world.

In the exogenic view, there is also the duality of mind and world. However, within the endogenic view there is an emphasis on the individual's intrinsic capacity to reason, apply logic or apply conceptual processing. The theorist is interested in the human's mental state and his or her innate knowledge. Endogenists include Chomsky with his theory of the innate knowledge of language, Moore on moral development, and Kant with his theories on causality and number (Gergen, 1995).

Social constructivists believe that language is the only way that people have of understanding the subjectivity of others. They believe that authors do not own their words but meaning comes from the relationship of words to each other and of a shared tradition and negotiated agreements within a particular culture. Social constructivists believe that learning about the world does not take place in a social vacuum but is shaped by the medium used for its exploration, that is, language. People use language and culture to help them think and imagine. Phrases such as 'shut the door and keep the cold out', and 'to feed the plants', provide, through culturally accepted metaphor, ways of representing the world. Language, whether spoken, internal or written, is culturally embedded. Language is also the medium through which people interpret and communicate their experiences of reality. This view of a social construction of reality places the educator not as the initiator of a conversation, where he or she knows the script, but as the participant in a conversation that is already underway when the student is encountered and where the educator has no knowledge of the previous discussions.

Both radical and social constructivists are wary of the exogenic or empiricist paradigm of knowledge creation. Each questions the view that knowledge is something that is built up within the mind of a dispassionate observer. Each questions the authority traditionally accorded to behavioural science and to educational processes that are dependent on the behaviourist epistemology of knowledge creation.

Vygotsky

The Soviet psychologist, semiotician and teacher Lev Semyonovich Vygotsky has had an important impact on our understanding of behaviour and learning. His work, according to Wertsch (1985), can be identified by the three themes that form the core of his theoretical framework. These are a reliance on a genetic or developmental method, that higher mental processes in the individual have their origin in social processes, and that mental processes can be understood only if we understand the tools and signs that mediate them. Wertsch (1985) describes Vygotsky's genius as being able to tie various strands of inquiry together so that the individual is immersed in the sociocultural setting in which they function. It is this integrative approach to social, semiotic and psychological phenomena that has relevance to us 60 years after his death.

> To encompass in research the process of a given thing's development in all its phases and changes … from birth to death… fundamentally means to discover its nature, its essence, for it is only in movement that a body shows that it is. Thus, the historical study of behaviour it is not an auxiliary aspect of theoretical study, but rather forms its very base. (Vygotsky, 1978, p. 128)

The fundamental claim in Vygotsky's genetic or developmental analysis is that human mental processes can only be understood by considering where and how they occur in growth. In this, he contrasted his approach with those that look at psychological phenomena without regard to the individual's development and identified several major transition points in the development of an individual in terms of the mediation utilised. Vygotsky argued that mental processing of information involves a social dimension which is first studied through a social setting namely, speech. Vygotsky was influenced by the work of Piaget (Wertsch, 1985) and his approach is constructivist.

Zone of Proximal Development

Another theme that Vygotsky developed is that of determining cognitive ability. He described how previous assessment involved having the student undertake standardised problems. By noting which problems the student had been able to solve the researcher has an indication of the student's mental age. Vygotsky tried another approach with a range of children of the same age:

> We gave each of them harder problems than he could manage on his own and provided some slight assistance: the first step in a solution, a leading question, or some other form of help. We discovered that one child could, in cooperation, solve problems designed for twelve year olds, while another could not go beyond problems intended for nine-year olds. The discrepancy between a child's actual mental age and the level he reaches in solving problems with assistance indicates the zone of his proximal development…. This measure gives a more helpful clue than mental age does to the dynamics of intellectual progress. (Vygotsky, 1986, p. 187)

Because learning involves more than imitating what is shown, Vygotsky believed that in order to learn one must be able to step from what is already known to something new. "With assistance, every child can do more than he can do by himself – though only within the limits set by the state of his development" (Vygotsky, 1986, p. 133). Vygotsky, however, does not negate the role of repetition and drill in learning: "They bring out the specific human qualities of the mind and lead the child to new developmental levels … imitation is indispensable" (Vygotsky, 1986, p. 133).

Vygotsky investigated the student's understanding of everyday and scientific tasks and found that, as long as the curriculum supplies the necessary material, the development of scientific concepts runs ahead of the development of spontaneous concepts. He asked why this should be and proposed that because children lack awareness of their own concepts, they cannot use them to operate at will. With scientific tasks, however, the teacher explains, supplies information, questions, corrects and makes the student verbalise the tasks; the student is then able (with the invisible help of an adult) to solve scientific problems much earlier than everyday problems. Vygotsky proposed that children's development of spontaneous concepts proceeds upwards, and the development of their scientific concepts proceeds downwards.

Vygotsky's proposition has been developed by West and Pines (1985), who identified two sources of knowledge in the individual. The first is interaction with the environment and intuitive or naïve knowledge. West and Pines believe that a person's sense of environment is acquired by language, culture and by interaction with other individuals and this is acquired in a haphazard manner with no particular direction. The second source of information is formal instruction, disciplined knowledge or school education. This is someone else's interpretation of the environment, someone else's reality. Learning in their view is how learners make sense of the inputs. West and Pines have developed a metaphor for their model using two vines, one growing up and the other growing down. School learning is represented by the vine coming down and interaction with the environment or culture represented by the vine growing up; genuine conceptual learning they believe occurs when the vines inter-wind and at this point the source of the particular vines can no longer be determined. This view of upward moving and downward moving understandings could help explain why some students do not see the relevance of the science undertaken in the classroom to their outside lives during the junior years of high school.

Constructivism and Science Teaching

The relationship between a student's schemes of understanding and schemes available through culture and language has been explored in science. As students grow, they actively search for regularities and meanings in situations and come to the science classroom with developed ideas or schemes about the natural world (Bauersfeld, 1988). Ausbel (1968) calls these conceptions and preconceptions: Driver and Easley (1978) introduced the term alternative frameworks in an attempt to capture the coherence of students' preinstructional knowledge and the consequent difficulty of changing students' conceptual understanding through teaching. For example, students have had experiences about what happens when they push, pull, drop or kick an object and have used these to develop ideas about how things feel and move. It is possible therefore for learners to have two realities for a word such as work until he or she is able to undergo conceptual change to integrate the two realities. Constructivists view genuine conceptual change as occurring when learners are able to make sense of school knowledge through integration and differentiating information (Hewson, 1996a). Until there is this integration, real world understandings can dominate the interaction between school and self-understanding (West & Pines, 1985).

When students are involved in an activity in a science class, they are drawing on not just what they experienced in that science class but also on their pre-existing ideas of the world. Learning involves an interaction between the schemes in the students' heads and the experiences provided (Driver, 1989). If the experience fits with the student's expectations, little change is required in the student's schema to accept the new idea. On the other hand, the experience may be novel and the student may have to change his or her schemes to fit the new idea. The process of using and testing current ideas in a new environment involves the learner in active engagement, drawing on current schemes, relating them to the task at hand and perhaps reorganising them.

The early schemes that learners develop about the world are often deep-rooted and often do not change over the student's time at school. The schemes may also remain after university undergraduate or postgraduate study (Coll & Treagust, 2000). Students show a marked reluctance to abandon schemes that have worked well for them or, if they do change, this may not be in the scientifically accepted direction (Cosgrove & Osborne, 1985). There also is evidence that a significant number of students who have altered their schema to fit the orthodox view regress to their previous notion or to a scheme similar to their previous notion after a short time (Coll & Treagust, 2000; Cosgrove, 1995; Happs, 1985).

The science that is taught in the classroom is public knowledge and when people learn this they interpret this and internalise it in their own way to fit each individual's private understandings. A syllabus defines those parts of the public knowledge that are to be taught. Teachers have a private understanding of the public knowledge that they try to share with their students. The resultant students' private understanding of public knowledge will be poorer than the teachers' knowledge as the student is unable to internalise all the pieces of information presented (West, Fensham, & Gerrard, 1985).

Science as a Social Construction

Language is the means by which people construct their reality within their society. The notion of an objective reality against which observations can be checked is not possible because such a reality is merely another social construction. The current dominant view is that although there is an external world people do not have access to it. Tobin (1991) believes that because our senses are subject to a translation process in our cortex this translation is affected by an individual's chemistry, previous experiences and reactions to them. An individual's senses are embodied and so all our experiences are essentially subjective. Knowledge is therefore a construction of reality and adapted as a result of experiences and reflections (Gagne, 1995).

If viewed from this framework, then science as public knowledge is not so much about discovery as about a carefully examined construction that exists in textbooks and scientific papers (West et al., 1985), that is, it is defined and definable. Scientific ideas do not result from direct interaction with phenomenon but also pass through a complex process involving communication and checking through major social institutions of science before being validated by a scientific community. Scientific theories are constructs of the known world, not of the world itself, and may be wrong. Indeed, we live in a construct of theoretical entities such as atoms, electrons, ions, fields and fluxes, genes and chromosomes, and are organised by ideas such as evolution. These constraints take on a reality separate from truth which constructionists assume will be forever elusive (Driver & Oldham, 1986). The social construction of science means that individuals cannot discover ideas about science; learning in science means being initiated into the culture of science.

Subjects can hold multiple views of the same concept, partly due to the student's schemas being packaged in much smaller pieces than the physicist's (or expert's) knowledge because each schema is activated only in certain contexts (diSessa, 1988). This difference can create tensions both between students and within students (Clement, 1987). Coll and Treagust (2000) describe how models of metallic bonding changes as students progress in age and education. This result is similar to that by Snyder (2000) who found that a hierarchy of models held by physics experts was dependent on their educational level and academic expertise. Coll and Treagust

(2000) believe that learners are content with less powerful models as they have no need for a more powerful scientific theory at an earlier stage of understanding.

Teachers try to draw on students' conceptions when they play individual student conceptions off against each other; encourage controversy and develop tensions centred on the opposing views held by different students. This tension has the potential to motivate and involve students in actively reviewing and testing their conceptual framework according to Freidl (1986).

ANALOGIES

Models and Analogies

The Concise Macquarie Dictionary (Delbridge et al., 1991, p. 72) defines analogy as "an agreement, likeness or correspondence between the relations of one thing to another; a partial similarity in particular circumstances on which comparison may be based". Merriam-Webster's Collegiate Dictionary (2001) [Electronic version] defines analogy as a "resemblance in some particulars between things otherwise unalike". Duit (1991) supports this definition of analogy when he describes an analogy as a relation between parts of the structure of two domains.

A useful working definition of an analogy is that it is a correspondence in some respects between concepts, principles, or formulas otherwise dissimilar. More precisely, it is a mapping between similar features of those concepts, principles, and formulas (Glynn, Britton, Semrud-Clikeman, & Muth, 1989). Treagust (1995) identified a working definition of an analogy as being a correspondence in some useful respects between concepts, principles, or formulas otherwise dissimilar. Glynn (1991) defined an analogy as a process of identifying similarities between different concepts. One concept, which is familiar, is referred to as the analog and the other concept, which is unfamiliar, is known as the target. Usually the target is the scientific concept. Glynn (1991) explained that while the terms analogy and metaphor are frequently used interchangeably, analogy is used more often in science and technology situations where meaningful understanding is the outcome while metaphor is used more often in a literary setting.

Scientific models can be theories to explain observations or they can be a picture intended to explain a theory more lucidly (Lacey, 1996). Replicas, scale models and analogies are familiar examples of scientific models used to more clearly explain theories or concepts (Hesse, 1967). The relation between model and the thing being modelled can be said to be a relation of analogy. So, simplistically, science analogies are a special group of scientific models.

Collins and Burnstein (1989) have identified three different types of analogies dependent on the relationships being compared which they refer to as systems analogies, concept analogies and property analogies. Systems analogies refer to relationships such as the solar system and an atom, while concept correspondence analogies relate to decisions about the properties of two concepts, for example, if an x is a y. Property correspondence analogies compare a particular property of two concepts such as whether a three inch disc is more like a dollar coin or a pizza. Duit (1991) looked at analogies as being verbal, pictorial/verbal, personal bridging and multiple and believes that the personal bridging, which can include role plays such as students being the red blood cells in the glomerulus of a nephron, is effective in teaching the structure and function of the kidney.

A good analogy needs to be explanatory, that is a number of features should be compared, and there needs to be a similarity and conceptual significance in the features. Limiting an analog to only one feature may not, however, necessarily reduce its effectiveness; a good example of this is comparing the moon to a mirror where 'the moon is like a mirror to the sun'. Poor analogies are those where few students are familiar with the analog; for example, few students in America are familiar with plum puddings or billiards, the standard analog for atomic analogies (Treagust, Harrison, & Venville, 1998).

Analogous reasoning can diminish or lead to a misunderstanding if features do not correspond; for example, electricity may be perceived to leak out of wires if the hose and water analogy is used without attending to limitations. Another reason why analogies are misleading is when vocabulary or linguistic structures are used outside the student's range. One example of this can occur with rhetorical questioning, where a question or statement is asked for a purpose other than to obtain the information the question asks, for example 'It doesn't matter that we are producing chemicals that will not degrade over reasonable timescales'? Rhetorical statements can be misinterpreted by students as fact and, in a similar manner, student awareness of the failure of analogies to map against all criteria of the target can be interpreted by students as fact and lead to conceptual confusion. Teachers and students need to be aware that all analogies will eventually fail if the comparisons are taken too far (Osborne & Freyberg, 1985).

Analogies in Science

The use of models and analogies is an essential trait of Galilean science according to Del Re (2000) who described how Galileo used what Einstein called a *Gedankenexperiment* [a thought experiment] to establish the foundations of mechanics by considering flies in a ship in perfect uniform motion. Thought experiments are a powerful tool in learning and arguing science. Reiner and Gilbert (2000) described how Poisson in 1818 used a thought experiment to resolve the apparent contradiction between Fresnel's wave theory and the particle theory as argued for by Laplace, Poisson and Boit. Poisson, arguing against the wave theory, suggested doing a thought experiment that placed a circular obstacle perpendicularly to the axis of a beam of light from a point source and viewing the centre of the resultant shadow. Poisson thought it would be dark, arguing that if light were a wave, the wave would arrive in phase at the periphery and thus combine at the centre of the shadow forming a bright point; for him, a most unlikely scenario. Subsequently, this experiment was carried out and a bright spot was indeed found at the centre of the shadow and the wave theory became accepted for explaining diffraction of light. Thought experiments are able to support conceptual change and are able to tap a fundamental process of learning where students use imagery along with logical inference and conceptual knowledge in creating new knowledge (Sorensen, 1992).

Analogies allow students to link discrepant elements together and play an important role in scientific discovery and insight. In discussing this as an important role of analogies, Glynn (1991) believes that analogies are not mere aids to the establishment of theories, but are an essential part of the theories. Models and analogies are, according to Glynn (1991), the relation between a sensible reality and the way that science derives knowledge.

Although teachers and students may not be aware of it, analogies underpin the teaching and learning of science. A teacher explains a concept and watches the class. Some students nod, some smile and others look confused. The first thing the teacher does is to think of a way to explain the concept and relate it to the students' experiences. The teacher may simply describe Rutherford's model of the atom as like chocolate chip ice-cream, or if describing folding in geology pick up a piece of paper and liken it to pushes on either ends of the paper. However, Treagust, Duit, Joslin and Lindauer (1992), in observing 40 science lessons, noted few analogies used by the teachers.

Treagust (1995) explained that by choosing an analog that is familiar to students it is possible to map and categorise those attributes which are shared and increase the use of the analogy in concept development. However, it is also important to map those features that the analog and target do not share because here incorrect generalisations and learning can occur with analogical use.

Analogies have always had an important place in traditional science. Clement (1988) described one of the most extraordinary as being that proposed by Robert Hooke and Isaac Newton in the seventeenth century. They claimed that the moon falls to the earth just as an everyday object (such as an apple) does. To a modern physicist this may seem more like an obvious fact than a creative analogy, but to advocate such an idea in Newton's time was not obvious at all. Other notable users of analogies were Johannes Kepler who developed his concepts of planetary motion from the workings of a clock, Christian Huygens who used water waves to understand light phenomenon, and Kekule who developed the idea of the benzene ring from his dream about a serpent biting its own tail (Treagust, 1995).

Closer to our time, Campbell (1957), in the preface to his monograph *Foundations of science: The philosophy of theory and experiment,* stated that in order for a law to be valuable it must display an analogy. He continued: "It is often suggested that the analogy leads to the formulation of the theory, but that once the theory is formulated the analogy has served its purpose and may be removed and forgotten. Such a suggestion is absolutely false and perniciously misleading" (p. ii). This monograph was planned in 1904 and originally published in 1920 and so places the use of analogy within the well-established tools of science education.

Analogies are the tools with which links are made between the known and the unfamiliar allowing teachers to harness their students' thought processes. Thinking is a complex activity that involves conscious and automatic processing of information. While automatic processing occurs without conscious effort or monitoring of effort, and can even be combined with other concurrent mental activities without loss of efficiency, conscious processing is voluntary, and according to Cohen (1983, p. 127), "is often effortful". Cohen (1983) used this distinction to discuss the difference between intuitive thinking and logical and rational thinking. Logical thinking can be described as conscious, analytical, sequential and orderly; intuitive thought is not available for introspection. This does not mean that the two processes are separate entities but they are mutually independent.

Students' prior knowledge is recognised as playing a crucial role in learning and determines the meaning that students derive from instruction. Teaching which does not build on a student's pre-existing knowledge and understanding will fail to produce meaningful learning. The use of analogy is a way for the learner to draw on his or her existing knowledge and give meaning to incoming information.

Brown (1993) stated that there are benefits in the use of analogies for engendering conceptual change. He believed that there are many reasons why the use of analogies can be helpful: they can assist in constructing more abstract representations and they help or enrich, or further enable, solidification of representations to develop. Brown (1992) also believed that analogies help move students from an alternative or naïve conception to an accepted scientific conception. The use of multiple analogies allow for the bridging of conceptual change by enriching the student's representation with previously unobserved or unobservable structures and mechanisms. While he acknowledged the problems of overgeneralisation, he believed that students engaged in the creation of analogies would be assisted in their conceptual development.

Larkin, McDermott, Simon, and Simon (1980) hypothesised that students need to develop knowledge at three levels, namely, naïve, physical and mathematical representations. According to Clement (1987), these levels of knowledge enable experts, unlike most novices, to problem solve and generate and elaborate a qualitative representation for the problem situation.

HIGH ABILITY STUDENTS

Historical Understanding

Intelligence is a construct that is widely accepted but is more difficult to define and according to Richardson (1991) is one of the most slippery and elusive of ideas. The Chinese, as early as 2200 B.C., were aware of the concept of intelligence and had developed a series of competitive examinations to select outstanding people for entry into the civil service (DuBois, 1970). Within the European context, Plato saw intelligence as the ability to comprehend relations and to make abstractions, and like the Chinese saw it as a practical concept needed to run the state. For Aristotle, a generation later, intelligence was a natural attribute of all citizens (excluding slaves) and was an attribute of people only and could be developed through teaching which meant it developed with experience and over time. The Romans borrowed the concept from the Greek doctrine to suit their needs and it is from the Romans that the modern term originates – a compound of *intus lego*, meaning to read within me or to read mentally.

In the Middle Ages, with the rise of feudalism and the strength of the Church, it was important for people to know their place – to be obedient to established authority. During this time, the writings of scholars resulted in the idea of intelligence becoming associated with ethical, political and social questions that eventually pervaded education. Charlemagne decreed education, hitherto haphazard and private, should be the concern of schools throughout Europe under the watchful eye of the Church. A student's response to this instruction became an important criterion of intelligence. Response to schooling and the distinction between bright and dull pupils was becoming a test for intelligence over 1000 years ago (Richardson, 1991).

By the sixteenth century, social and economic changes were taking place all over Europe and there was a demand for freedom and equity and the writing about intelligence changed to discussion of method and practice (Richardson, 1991). With the rise of the manufacturing class and new degrees of exploitation, new economic inequities emerged. The search for new resources and markets entailed the subjugation of societies and the rise of the institution of slavery. Herbert Spencer (1855) tried to add a biological dimension to the meaning of intelligence when he linked the concept to Social Darwinism.

The term genius is linked today to an extraordinary degree of intellect, and Simonton (1999) describes how the term originally signified a guardian spirit that determined the unique nature of an individual and only later was it used to describe what was special about a person. Previously the term genius was used to describe the unique or special features of a time or age, for example, the genius of the Elizabethan age, whereas now it is used to describe people of exceptional talent such as Newton. Due to the association with intelligence, at the beginning of the nineteenth century psychologists tried to build a more precise definition of intelligence and developed the intelligence test.

Alfred Binet developed a measure of intellectual ability that was transformed into a measure of IQ, the intelligence quotient. Average was taken to be 100 and scores above or below the baseline indicated a person was above or below average in intellectual ability. For many years the accepted method for identification of gifted students was the student's score on an individually administered test of intelligence, such as the Stanford-Binet test of intelligence. Using this test, the definition of giftedness is an IQ score of 136 or higher (Bracey, 1994). The ability of a single test to identify gifted individuals today is challenged by psychologists as the concept of intelligence is now seen as multifaceted (Shaughnessy, Jausovec, & Lehtonen, 1986).

Intelligence Today

Due to genetic variation, there are large differences amongst people, which include differences in information processing abilities related to differences in an individual's nervous system. Particular individuals consistently display performances in various fields that amaze observers by the degree of expertise involved. Such people are referred to as gifted or talented or are said to display gifts or talents (Cropley, 1993b). Within the field of gifted education, these terms are particularly important because they define the target population; yet according to Gagné (1995) no consensus seems to exist about their exact meaning. Traditionally, the notion of giftedness refers to the cognitive domain such as memory or clever thinking, especially associated with school settings or school-like situations, as a gifted mathematician, a talented musician or a gifted linguist. The definition of giftedness has been expanded somewhat and now includes outstanding performance in any area, for example exceptional sporting performance such as swimming or athletics. It has also been broadened to include out of school giftedness such as leadership, that is, gifts in the personal effective and motivational domains.

Tannenbaum (1986) believed that developed talent only occurs in adults and so proposed a definition of giftedness in children as denoting “their potential for becoming critically acclaimed performers or exemplary producers of ideas in spheres of activity that enhance the moral, physical, emotional, social intellectual, or aesthetic life of humanity” (p. 22). Here, Tannenbaum appears to associate giftedness with potential and talent with developed ideas. Renzulli (1986) presented a triad of compulsory ingredients in his definition:

> Gifted behaviour consists of behaviour that reflects interactions among three basic clusters of human traits – these clusters being above average general and/or specific abilities, high levels of task commitment, and high levels of creativity. Gifted and talented children are those possessing or capable of developing this composite set of traits and applying them to any valuable area of human performance. (p. 73)

Renzulli’s definition is dependent on students exhibiting traits and ignores underachievement (Gross, 1999). This bias may be why there has been less written about the quantification of giftedness such as how much of a skill an individual possesses and why there has been more of a qualitative approach to giftedness over the past 10 years (Cropley, 1993b). There has been an increasing emphasis on the cognitive processes, especially the processes that define them and the mechanisms which direct, accelerate or decelerate and guide these processes extending into the pluralisation of intelligence as outlined in Gardner's (1998) theory of multiple intelligences. Gardner believes that people have the ability to analyse in at least seven different areas: linguistically, logical-mathematically, musically, spatially, kinesthetically and interpersonally and that intelligence cannot be measured with accuracy independent of the particular context where an individual exists. Gardner also believes that intelligence is distributed across individuals. In this context, he believes that individuals do not work or live in isolation, and that there is the assumption that there will be other individuals within their environment with whom they can interact. The concept of a distributed intelligence builds on the notion that an individual does not have all relevant knowledge and to solve a particular problem input from many people is required.

Cognition

Cognition is defined by Cropley (1999) as being concerned with the ways that people organise, process, store and use information. Thinking is the process through which symbols are constructed, revised, linked with other symbols, reorganised, and applied to abstract or concrete situations. Thinking involves processes such as exploring, reorganising, organising, and coding, as well as forming structures such as patterns, categories, networks and systems, that result from these processes. To these must be added control mechanisms such as styles, strategies or tactics that guide the processes and affect the kind of structures to which they lead.

Noncognitive approaches to defining giftedness emphasise motivation, values and attitudes, and personal characteristics such as self-image: great expertise requires not only skills and abilities but also the confidence in one's ability to master the area in question. The achievement of exceptional expertise also requires the investment of large amounts of energy and time. It is also apparent that giftedness involves a strong social element. The society and its subgroups play a major role in deciding which achievements will be regarded as prodigious and those that are regarded of less value.

Creativity

In the 1950's and 1960's, as the United States of America tried to match the scientific achievements of the Soviet Union, there was a renewed interest in giftedness and it was found that a measure of IQ was not in itself an adequate measure and creativity was also an important indicator. Cropley (1967) describes how highly intelligent university students attained good marks but were constantly surpassed by students high in both characteristics. The essential features of creativity included: forming associations, recognizing similarities, constructing metaphors, carrying out transformations, selectively directing the focus of attention, and seeing the abstract aspects of the concrete (Cropley, 1993a). Similarly, Simonton (1999) states that creative people produce associations and recognize them as such. He believes that creativity involves the production of a large number of associations more or less randomly and these chance occurrences represent what is required to solve a problem. Weisberg (1986) believes that the associations are not random but chains of ideas and associations in a long series of strictly logical small steps with knowledge the vital key. Knowledge provides rules which can tell blind alleys from promising approaches or for choosing between competing lines of attack, evaluating emerging solutions and deciding the best way to continue.

Creativity is now accepted as an element of giftedness and it appears that the ability to produce novelty is linked to the ability to think creatively. Cropley (1999) discussed the role of thinking in creativity, distinguishing between open and closed thinking; Gestalt psychology considered differences between reproductive and productive thinking and deBono (1970) differentiated linear and lateral thinking. The ability to think creatively is facilitated by higher order cognitive systems and involves both assimilation and accommodation. Assimilation takes place when new information is incorporated into a person's existing conceptual framework; accommodation involves the reorganisation of existing frameworks to fit that information. Wallas (1926) also identified a stage of incubation of creative ideas during which ideas seem to bubble up and emerge from no-where.

A study of scientific genius also includes tenacity and perseverance as seen in the work of Charles Darwin (Desmond & Moore, 1992). Other aspects also include personality traits such as flexibility, sensitivity, tolerance, a sense of responsibility, empathy, independence and a positive self-image as well as a fascination with the subject matter (Farisha, 1978). In his three ringed model of intelligence, Renzulli (1986) developed a map of giftedness as the area of overlap of three concentric circles where the circles represent creativity, intelligence, and task commitment. Creativity is now always included in an understanding of giftedness with knowledge still an important component. A gifted student must be well endowed with facts, for example, a creative individual may be able to produce a witty phrase in a foreign language, but first he or she needs to learn thousands of words in that language.

A Differentiated Model for Giftedness and Talent

Eysenck (1995) has developed a model of intelligence which sees a person's functioning intelligence as having many inputs, these inputs increasing as their functioning intelligence at adulthood develops. Initially, an individual's intelligence is determined by biological intelligence, determined by genetics, biochemistry and psychology, this in turn is affected by cultural factors including education, socioeconomic status and family upbringing. The resultant social intelligence is then superimposed upon by factors such as motivation, culture, social and illegal drug habits, coping strategies, family upbringing, nutrition, experience, health, personality, mental disorders and family background. The complexity of inputs increases as an individual develops.

One of the most influential models of giftedness and talent, according to Gross (1994), has been developed by Francois Gagné. Gagné's differentiated model of giftedness proposes a distinction between giftedness and talent and comprises five aptitude domains, namely, intellectual, creative, socio-affective, sensor motor and others such as extrasensory perception. Each of these domains is largely determined by the person's genetic endowment and can be seen in specific activities a child undertakes. Talents emerge as the child transforms these high aptitudes into well-trained skill characteristics. This process is facilitated or hindered by the action of intrapersonal and environmental catalysts. Within the intrapersonal catalysts, Gagné included physical and psychological factors, all to some extent under genetic control, and also motivation and volition that guide the individual through obstacles, boredom and occasional failure. The environmental catalysts include family, personality, parenting style and teachers. The action of these clusters of catalysts is responsible for an individual moving from being just gifted to being talented (Gagne, 2000).

The Columbus Group Definition

A recent definition of giftedness was proposed by an American group of psychologists, led by Linda Silverman (1998), called the Columbus Group. This group believe that the concept of giftedness originated in the field of psychology, specifically as part of the study of individual differences but over the years the link with psychology has been lost and has become embedded in education. The Columbus Group believe that the failure to find a differentiated curriculum for the gifted has led to a rejection of the concept of giftedness *per se*. For example, in recent years there has been an outcry against any special provisions for the gifted with many, in countries like Australia, believing these provisions to be an esoteric endeavour rather than being part of the educational mainstream (Passow, 1984). The Columbus group's psychological definition states that giftedness is an asynchronous development in which advanced cognitive abilities and heightened intensity combine to create inner experiences and awareness that are qualitatively different from the norm and this asynchrony increases with increasing intellectual capacity. This uniqueness requires a different approach to parenting, teaching and counselling in order for it to develop optimally. Consequently, gifted children develop in an uneven manner, they are more complex and intense than their age-mates, feel out of sync with age peers and the age-appropriate curriculum. Their greatest need is each other in an environment where it is safe to be different (Silverman, 1997).

Mental Processing

Jausovec (1997) explored the relationship between EEG (electroencephalography) activity and giftedness to gain some understanding of the thinking patterns of gifted and other individuals. This work is based on the idea that alpha brain wave activity is inversely proportional to mental processing and is prefaced on the concept that hemispherical asymmetry is related to intellectual giftedness. Research findings indicate that the right hemisphere specialises in Gestalt perception, and is primarily for synthesis. The left hemisphere includes speech, appears to deal with logic and is the analytic part of the brain. Jausovec's work was limited in that he used a maximum of four electrodes that were restricted to the temporal and parietal regions of the brain of 34 right-handed students taking a course in psychology. Seventeen of the students had been awarded scholarships for giftedness, a scholarship awarded to about 1% of the most gifted students in Slovenia on the basis of high ability scores in intelligence tests with IQ's above 130 using a Wechsler Intelligence Scale for children (WISC). In addition, the students needed to exhibit outstanding achievement in science, mathematics or in an artistic domain.

The limited results do indicate differing processing of information in the two groups of individuals. While in a relaxed state, the alpha brain wave activity is greater over the right hemisphere in the gifted students than for those of the control group. A finding that indicates greater neuronal activity in the left, logic hemisphere. This pattern changed considerably when the students were problem solving; the gifted students displayed less left hemisphere activity than did the control group and had greater right hemisphere activation. This was explained by the gifted students being more actively involved and perhaps better able to structure problems and so reduce their complexity than were the control group of students.

Expert/Novice Approach to Problem Solving

In order to better understand how gifted students problem solve, researchers have tried to determine how experts in a field approach problems as compared to novices in order to discover the differences between the two groups in their knowledge basis, strategies, and metacomponents. What do experts possess that novices lack? The main difference is that experts have more knowledge than novices but they also differ in the way they solve problems. Larkin et al. (1980) found that in physics, novices start from the unknown and work towards the givens, whereas experts work from the givens to the unknowns. Experts were able to generate from the givens the quantities required to generate the solution. Rohwer and Thomas (1989) determined that experts spent far more time than novices in reconstructing representations of the problems whereas novices embark immediately on a course of action and persist in that course. Schoenfeld and Herrmann (1982) described this as reading a problem, picking the direction and then working on it until the time runs out. Expertise requires a great deal of content knowledge, the organization of which reflects a deep understanding of the subject matter. It appears that experts are able to determine familiar patterns that guide them to the relevant knowledge about appropriate actions and strategies. Larkin et al. (1980) emphasised, however, that expertise cannot be obtained effortlessly because "the extent of the knowledge an expert must be able to call upon is demonstrably large and everything we know about human learning processes suggests that, even at their most efficient, those processes must be long exercised" (p. 1342).

American Policy on Gifted and Talented Education

In the autumn of 1957, the Soviet Union launched the first Sputnik satellite and this event simultaneously launched a debate in America, as well as Australia, about the quality of education, particularly the quality of science and mathematics education, to produce people who would be able to lead America in what was then the Cold War. The American public believed that it was in peril from outside forces if the education system was not improved (Ross, 1997). Testing programs to identify able students were put into place and these students were channelled into mathematical and scientific fields to improve America's ability to win the Cold War. However, with the success of the space program interest in these programs waned. The 1960's and 1970's saw the rise in demands of the individual, particularly the disenfranchised, and the education of exceptional students was supported federally until 1981. In 1988, the United States Congress reviewed this area and re-established a small program for the gifted education of students that eventually became supported by legislation. The current direction is to establish curriculum standards and high level learning opportunities that match each child's developing talent with appropriate experiences in order for the child to grow (Ross, 1997).

NSW Government Strategy for the Education of the Gifted and Talented

It has long been the stated aim of education in New South Wales that each child should have the opportunity to achieve his or her potential (New South Wales, 1988). In 1988, the New South Wales Government set up a committee to review schools under the chair of Sir John Carrick (1988) and reiterated the view that government schools have a responsibility to educate all students to their full potential and that the education of children of exceptional ability was not a luxury but a necessity. As a result of this review, the NSW Department of School Education developed a strategy to assist in the education of gifted and talented students (New South Wales Department of School Education, 1991) which among its recommendations listed, "Regions and schools have a responsibility to co-ordinate provisions for gifted and talented students" (p3). The Acting Director-General of School Education, Ralph (1991), went on to state "that teachers have a responsibility to select a variety of teaching strategies for inclusion in programs for the range of gifted and talented students in their class" (p. 3).

The NSW Department of School Education (1991) in its implementation strategies described appropriate teaching/learning strategies as providing opportunities to think creatively; guiding students through problem solving processes, open-ended questions, activities and assignments; engaging in group work, which allows for leadership, cooperative decision-making and student-initiated perspectives; doing contract work, where students negotiate the contract components; conducting individual research; and mentoring as well as providing individualised enrichment programs and extension of the curriculum. The document goes on to describe the placement of these students in specialist classes or schools that have a responsibility for providing appropriate programs for gifted and talented students (New South Wales. Department of Education and Training, 2002) [Electronic version].

New South Wales has a long history of provision of specialist schools, North Sydney Boys High School being founded in 1913 as a school for academically streamed boys. Entry into these schools currently is controlled by the Selective Schools Unit of the Department of Education and Training and is by performance in the Selective High Schools Test in English, Mathematics and General Ability, together with the primary school's assessment of the student's performance in English and Mathematics. Other evidence also may be taken into account before a student is offered placement in a selective high school. In 2001, over 18,000 students, or four percent of state government students (Gross, 1999), were enrolled in 17 fully selective high schools, six high schools with selective classes and four agricultural high schools offering selective placement in the New South Wales state school network. As of 2002, the Department of Education and Training extended selectivity with the creation of selective classes within six comprehensive state high schools.

Although the existence of selective high schools in New South Wales has been a continuing feature for many years, the educational advantages of placing a gifted student in a selective high school has been challenged by various organisations such as the teacher's industrial union which has included articles by its editor (Poulos, 1990) stating that:

> The Talented Child Brigade pushing their middle class wheelbarrow all the way to University…the sons and daughters of middle-class yuppies trying to steel (sic) more and more privileges under the pretensions of greater abilities bestowed on them not by their class but by god himself. (p. 8)

Vinson (2001) referred to old research which compared matched gifted and talented students in selective high schools and comprehensive high schools with respect to Leaving Certificate scores and found no differences in the students' results. These studies used old data and made no reference to the changed assessment procedures. However, these studies were cited by Vinson (2001) in his review of state education, funded by the NSW Teachers' Federation, as evidence for an all-inclusive comprehensive education system. This issue is a continuing theme at election time where, for example, in 1997 the Teachers' Federation called on the state government to "reduce and eliminate selective high schools on the grounds that the increased welfare/discipline problems at comprehensive high schools (are) caused by the removal of their local, positive role models" (New South Wales Teachers Federation, 1997 (p. 12). These calls are not helped by an unpublished Department of Education and Training review of Manly High School in February 2000 which identified deficiencies in the administration, assessment and teaching of high ability students resulting in the schools' students not achieving Higher School Certificate results in line with their ability (Personal communications).

CONCLUSION

In this chapter the main contexts underpinning this thesis were introduced. The evolution of educational thinking from positivism through post-positivism and behaviourism to the post-modernist view that incorporates constructivism as a theory about knowing was presented. Piaget was introduced as an early researcher to examine the world from a child's view to see how children construct reality based on their individual experiences. Through the work of von Glasersfeld, the emerging tensions between the teacher as provider of facts and the teacher as facilitator was presented together with the emerging themes of radical and social constructivism. The impact of Vygotsky, the Russian educator on learning theory, and some of his work was discussed in relation to his influence on the direction of educational theory.

Analogies are the tool used to examine student understanding and this chapter has defined analogies and their role in a constructed science as well as their ability to support conceptual change.

This thesis is set within a selective high school, where the students are, by definition, high ability students. This chapter reviewed the historical view of intelligence as well as the current multifaceted theories where cognition is only one facet and creativity, as well as the input of education, the family and society and culture, are important contributing factors. How high ability students think and research on mental processing by gifted and talented (GAT) students, as well as on expert/novice approaches to problem solving, was introduced. The chapter concluded with a brief discussion of the reasons behind the interest in gifted education in America and the present situation in New South Wales.

The following chapter introduces the theoretical framework under which this thesis was undertaken as well as the methodology of the research.

CHAPTER 3

THEORETICAL FRAMEWORK AND METHODOLOGY

Empedocles was born about 429 BC in Acragas one of the most beautiful Greek cities in the ancient world until the Carthaginians destroyed it in 406 BC. Empedocles was amongst other things a poet, a seer and a physicist. Empedocles is attributed with many firsts. He is considered by Aristotle to be the founder of the science of medicine but he is best known for his belief that all matter is composed of four elements - fire, air, water and earth. This hypothesis dominated Western thought until the eighteenth century.

Empedocles believed in the finite velocity of light and developed a crude evolutionary theory on the evolution of the fittest. He also had a form of conservation of energy and a theory about constant proportions in chemical reactions. Why then did such prophetically correct ideas have such little influence on science? Why isn't Empedocles amongst the names all science students are introduced to as they trace the path of chemical knowledge? To warrant a place in history an idea has to fit within a theoretical framework or it loses its explanatory power and is lost in time… (Gillispie, 1971, p. 368).

OVERVIEW

This thesis has three main research questions that relate to student learning and have been investigated in a working classroom – Research Question 1: Can high ability students create their own analogies?, Research Question 2: What role do analogies play in learning?, and Research Question 3: How do analogies help students in concept development? This chapter presents the research paradigm which underpins this thesis, and the methodology using multiple, naturalistic case studies. The theoretical orientation of this research has also been informed by phenomenography and grounded theory and these are discussed, together with how they determined the route and method of analysis. The chapter includes a discussion of the setting at North Sydney Boys High School, a selective boys high school in Sydney, New South

Wales and the path and methods taken as the data were collected and analysed. The chapter concludes with a discussion of the reliability and validity of the collected data.

BACKGROUND

This classroom-based project began with no established rules to follow other than the necessity of looking at how students learn. Not all the observations undertaken are of equal value and observations were validated by the behaviour of the class and the logical extensions of those observations. The process of observing, recording, analysing, reflecting, dialoguing and rethinking were all essential parts of the naturalistic research process undertaken for this project. All are validated by their contribution to understanding the classroom in which the events took place.

Naturalistic research, according to Roman (1992), is a way of immersing the researcher as a participant-observer within a group in order to reflect the beliefs and way the group functions so as to be able to depict the group as an entity. To clarify common knowledge within the classroom using this approach had a personal appeal. Romain (1992) described this form of research as one where the researcher holds in abeyance any prior political assumptions and theoretical commitments about what is happening in the context under study. The researcher entered the classroom to view anew the learning process occurring therein and to reassess her understandings about that learning. As a researcher, her role was to inductively generate hypotheses to explain observations and, as described by Schultz (1964), to find some overlap in assumptions, beliefs and world-views between researcher and the researched, which was reassuring given that the same society is inhabited by both the teacher and students.

The identification of data makes naturalistic research different from other forms of research; the data comes first and is used to construct patterns and hypotheses and then maybe a story. Naturalistic research is primarily a methodology of the field or natural settings where phenomena are studied first-hand over an extended period of time. Rist (1977) identified a series of procedures for those involved in naturalistic research that included gaining access to the site, adopting a role, collecting data through observations, interviews and document analysis, analysing data, seeking confirmation, and presenting the report. This is the sequence of activities followed by this thesis. Chapter three presents the methodology of the thesis and outlines the specific approaches taken in each step of the research. An outline of the research approach is presented in Table 1 and the terms presented in this table are used as headings to structure this chapter. The research procedures used to determine the research questions posed in this thesis are shown in Table 2.

Table 1: An outline of the research approaches taken in this study

Aspects of the research process	Approach taken in this study
Research paradigm	Constructivism
Theoretical orientation 1	Grounded theory
Theoretical orientation 2	Phenomenography
Setting	North Sydney Boys High School
Research design	Multiple case study
Data collection	Student evaluations Student assignments Student examinations Student examination review Student interviews
Data interpretation	Coding of evaluations Coding of assignments Coding of examinations Coding of examination review Coding of interviews
Trustworthiness	Credibility Triangulation
Ethical issues	Informed consent

Table 2: Summary of research questions and research procedures

Research question	Data type/collected	Data collection strategy	Internal validity	Data analysis
1. Can high ability students create their own analogies?	Qualitative/ Assignment component	Assignment	Triangulation & repeat observations	Phenomeno-graphic analysis
1a. What types of analogy do students create?	Qualitative/ Assignment component	Assignment	Triangulation & repeat observations	Phenomeno-graphic analysis
1b Can students deconstruct their own analogies?	Assignment component	Assignment	Triangulation & repeat observations	Phenomeno-graphic analysis
2.What role do analogies play in learning?				
2a. What type of analogies are the most effective for supporting conceptual change in students?	Qualitative/ Assignment questions Open ended writing	Assignment & Diary entries	Triangulation Credibility	Phenomeno-graphic analysis
2b. How long do analogies created in the classroom remain with high ability students?	Qualitative & Quantitative/ Examination questions	Examination & review	Triangulation	Description
2c. If students revert to alternative analogies, what happens to the original classroom analogy?	Qualitative/ Examination questions	Examination & review	Triangulation	Phenomeno-graphic analysis
3. How do analogies help students in concept development?	Qualitative & Assignment component Questionnaire	Assignment & Interviews	Triangulation & repeat observations Triangulation	Phenomeno-graphic analysis

RESEARCH PARADIGM

Constructivism

How does a researcher determine reality? There are various ways to proceed with research so that the conclusions can claim to be truthful. Reality is linked to various paradigms and within each are epistemological and ontological constructs that determine the researcher's methodologies and their interpretive framework. The various paradigms reflected in research of science over current time were introduced in Chapter 2, including constructivism which is the paradigm underpinning this research.

Nancy Friday in her book *My mother, myself*, referred to in (Guba, 1981), describes the effect of a paradigm in affecting a person's view of the world in a classic example of mother-daughter role modeling. Peggy early in her marriage is cooking a meal for her parents. Standing up to carve a leg of ham her new husband asked why she had sliced off eight to ten centimeters from the shank end of the ham before baking. Peggy answered that her mother always did it that way. Everyone at the table looked at Peggy's mother who replied that her mother did it that way and wasn't that the way everyone carved ham? Peggy phoned her grandmother the next day and asked why in their family the shank end of the ham is cut off, to be told that that was the way her mother did it. It happened that Peggy's great-grandmother was still alive, so a call was put through to her, and the mystery was solved. Once when Peggy's grandmother was a little girl and learning to cook they were baking a large ham and it would not fit in the oven so the shank end had to be cut off to make it fit.
Here is a story of four generations of women conforming to a set of routines that were no longer relevant. Each female was sure in her mind that the way she was proceeding was the right way. This story shows how procedures we choose to follow can incorporate less rational assumptions. Research paradigms can also incorporate unintentional assumptions that can effect the collection and analysis of the resulting data.

Constructivism underpins the paradigm within which this research project was developed. The aim of constructivist-interpretive inquiry is to understand and reconstruct the constructions that people (including the inquirer) initially hold as distinct from the positivist paradigm which sees the essence of enquiry to be explanation, prediction and control of the physical or human phenomena. Constructivists believe that knowledge is a construction about which there is relative knowledge amongst those qualified or competent to interpret the data (Guba & Lincoln, 1994). The purpose of this thesis is to understand the process of learning that high ability students undergo when they use analogies to support their learning. This purpose fits within the constructivist paradigm and guides and informs choices made in the methods of inquiry and methods of analysis of this research.

THEORETICAL ORIENTATION

The qualitative researcher may take on many roles as scientist, field worker, performer, and essayist. The many methodological practices of qualitative research can result in the researcher being viewed as a kind of professional do-it-yourself person as he or she uses the tools of his or her craft, employing a variety of methodologies, to construct meaning from an inquiry (Strauss & Corbin, 1990). In this thesis, two theoretical orientations – grounded theory and phenomenography – are used to determine the route and method of analysis of the data collected.

Grounded Theory

Generally research can be described as being inductive or deductive with regard to theory. Traditional or positivist research is generally deductive with regard to theory, that is, there is the statement of a specific theory or hypothesis before the research begins and the data collection is designed to test the hypothesis (Patton, 1990). Alternatively, grounded theory is an inductive approach to data collection and data analysis, initially developed by Glaser and Strauss in the 1960's, that aims to develop theory from the data collected by the researcher (Patton, 1990). Holloway (1997) claims that researchers use grounded theory to investigate interactions, behaviours and experiences as well as individual's perceptions and thoughts on them. Grounded theory stresses the importance of context in which people function, and the roles they adopt in an interaction.

The main aim of grounded theory is to generate theory from data, although Holloway (1997) does say that existing theories can be modified and extended by this approach. Grounded theory researchers start with an area of interest, collect the data and allow the relevant ideas to develop. According to Patton (1990), "grounded theory depends on methods that take the researcher into and close to the real world so that the results and findings are 'grounded' in the empirical world" (p. 67) while Holloway (1997) believes that rigid preconceived ideas that exist in the traditional position prevent development of the research and may impose a framework that blocks the awareness of major concepts emerging from the data.

Grounded theory techniques use constant comparison whereby the reader compares each piece of work with every part throughout the study for similarities, differences and connections. In this process, the themes and categories are identified and all the data are coded and categorized while major concepts and constructs are formed. The researcher then identifies major themes that link ideas to develop a story for the study. This form of study does not start with a hypothesis. Instead relationships are established and a working hypothesis is formed after collecting the initial data which is then checked against further data. The systematic, structured approach to data collection involved in grounded theory enables it to be descriptive and also have explanatory power.

The strength of this form of data collection and analysis is that the researcher needs to be intuitively aware of the situation to enable theoretical sensitivity to emerge. In this study, the researcher was a teacher immersed in the classroom and was embedded professionally as well as personally. Grounded theory allows a researcher to be located within a classroom where ease of access and available resources are not impediments to the research. The constant and continuing demands on a classroom teacher can create difficulties in planning the sampling prior to the research. Grounded theory allows for continuing decisions for data sampling to be made throughout the period of the research, these decisions are relatively easy to implement within this framework.

Charmez (2000) asserted that this methodology fits within the constructivist paradigm because it allows the data to emerge as connections between ideas become apparent. One criticism leveled at grounded research is that the approach can be seen to be too descriptive, with little emphasis on conceptualization. Strauss and Corbin (1990), however, state that it is not enough to describe the perspectives of the participants to develop a truly 'grounded' theory. Within grounded theory the researcher makes initial sampling decisions and then chooses a setting and participants to elicit the information required. Once the process has started, events and people are chosen to illuminate the developing theory. Sampling then takes place to the point of saturation when the theory developed best explains variation in the data (Holloway, 1997).

LIMITATIONS OF RESEARCH

A limitation of this study was that data collection, though expected to continue to saturation, was limited by the school year; hence, data collection ceased at the conclusion of the school year rather than at saturation. A second limitation in this research may be the small sample size which limits the number of cases showing general applicability of the findings; however, new understandings can emerge from classroom research that can have general applicability. A third limitation was the location of the research in a busy high school classroom which created constraints on the development and completion of instructional material. To overcome this, the materials developed in the Year 9 class were included as part of the normal assessment procedures.

PHENOMENOGRAPHY

Phenomenography, a term coined in 1979, was originally developed by a research group in the Department of Education at the University of Gothenburg, Sweden, to refer to the qualitatively different ways that people experience or think about various phenomena and is concerned with the relations that exist between humans and the world around them. Phenomenographic thinking is described in terms of what is being perceived and thought about and an effort is made to determine all the understandings that people have of a specific phenomenon and to sort them into conceptual categories (Marton, 1986). The results of phenomographical analysis are a finite set of categories which, with their relationships, are the means to explain the understandings of the learners.

Phenomonography provides techniques with which to analyse the products of people's lives to determine how they think about the world. The questions that phenomenography asks relate to the different ways of experiencing phenomena and how these are related to each other (Marton & Pang, 1999). The descriptions of people's experiences are the primary level of collection of data, these descriptions are categorised and so constitute the main result of the research.

Phenomenography as a methodology is concerned with changing human perception and has been a tool used to study conceptual change. It has, however, not put forward explanations or mental models of cognition, arguing that understanding is necessarily a human-world relation rather than the result of a specific cognitive functioning system possessed by an individual (Yan, 1999). Thus phenomenography is a methodological tool enabling researchers to develop ideas or schemes of the world they and their subjects inhabit. Using this tool, it is possible to view the mental processes that students undergo as they proceed through their experiences within their environment and so fits as a tool within the constructivist paradigm.

RESEARCH SETTING

The research took place at North Sydney Boys' High School (NSBHS), which was established in 1915, and is a government, selective school with strong traditions of academic excellence and of sports, the arts and community service. Entry to the school is on academic merit, as determined by a state-wide Selective Schools Entrance Test at Year 6 or by testing and school reports in Years 8-12.

The school is located on the lower north shore of Sydney. While there is currently no designated drawing area from which students come to the school, the majority of students live within 8-10 kilometres of the school. Other students, however, travel from much further afield, for example, from Avalon on the Barrenjoey Peninsular, to the inner city southwards and extending west to the north western suburb of Carlingford which is in excess of 20 kilometers from the school.

NSBHS enrolls 150 students in five classes annually in Year 7, maintains 150 through Years 7-10 and takes an additional 15-20 students in Year 11. The peak enrolment of 918 students has resulted in an overcrowded school on its small site where space both inside and outside the classroom is at a premium.

Junior classes in Years 7-9 science have a maximum of 30 students, while classes in Year 10 have 25 students. Senior classes have a maximum of 24 students and class sizes from 10-24 students depending on the location of the class on the timetable. There are 21 junior classes in Years 7-10, five in Years 7-9 and six in Year 10. About 80% of students continue with at least one science subject to the Higher School Certificate resulting in a senior school that has as many, if not more, classes than the junior school. There are four or five Physics and four or five Chemistry classes in Year 11 and the same numbers in Year 12 as well as one or two Biology classes, depending on the specific choices by students at the end of Year 10.

As a result of the selective nature of the school, parental expectations of the school and their sons are high, and to a large extent are fulfilled. The results in English, Mathematics and Science as measured by the 1997, Year 10 Reference Tests are very high. Overall, 71.2% of results were in the top 10% of NSW. The results in Science are even higher, with 81.7% students being awarded Grade A in 1997 compared with a range between 50.9% and 72.3% in the previous two years (Newsom, 1997). Many Year 12 students achieve University Entrance Scores above 98/100 as a result of the Higher School Certificate Examination, although there are students each year who achieve well below their potential. Of the 167 who sat the HSC in 1997, some 97% of students received offers of university course placement (Newsom, 1997).

There is a stable permanent teaching staff of about 60 at the school, with low staff turn over. One member of the Industrial Technology Department has taught at the school for over 30 years. The Science Department has 10 teaching staff, two of whom are the Deputy Principals. This staff stability is reflected in the science staff, three of whom have been at the school for over 10 years. Two of these teachers have extensive practical knowledge, one has worked as a geologist and another as an industrial chemist prior to entering the teaching profession. In addition, NSBHS has a high proportion of part-time teachers; the Science Department has one teacher on 3 days a week. The Science Department also has, at present, two full time casual teachers, one of whom has been in the position for three years.

In this thesis, the researcher was working as a teacher-as-researcher, a trend that emerged from the introduction of behavioural objectives in Great Britain in the 1960's (Anderson, Herr, & Nihlen, 1994). The advantages of this type of process are that the social processes and structures are understood within a historical context and theory and practice can be integrated. Wong (1995) and Newman (1992) describe the problems encountered as the researcher negotiates between the two roles. Both these researchers were university academics working as teachers while undertaking research. This thesis was undertaken the other way around where the researcher was a teacher and the research an additional role; the role of researcher is optional while the role of teacher is not. The problems which confronted Wong and Newman were not as pressing to the researcher because the theoretical framework allowed theory to emerge from the teaching.

RESEARCH DESIGN

Multiple Case Studies

The research design served to link the research paradigm to specific methods of collecting and analysing empirical materials (Denzin & Lincoln, 1994). The design comprised the skills, assumptions, enactments, and material practices that the researcher used as she moved to practice within a paradigm. The design employed to manage and organise the materials to be collected was a multiple case study.

Naturalistic research is dependent on context, which stems from the assumption that participants are linked by a web of interrelationships that both restricts and extends the applicability of the research (Erlandson, Harris, Skipper, & Allen, 1993). Case studies are one of the most common ways to undertake qualitative enquiry because they enable interpretation to be within a context (Denzin & Lincoln, 2000). According to Merriam (1988), case studies focus on a specific situation or phenomenon, they are descriptive and they are heuristic; in other words, they offer insights into the phenomenon being studied and as such fit within the qualitative or naturalistic framework. A deciding factor as to whether the case study is the most appropriate tool is whether it is a system bounded by time and space. The data collection within specific classes and using specific sets of data made this the appropriate tool for analysis of this project. In addition to these factors, Yin (1984) defines case study research similarly to Merriam (1988) but includes the provision that the inquiry has boundaries between the phenomenon and context that are not clearly evident. These cases investigate phenomena within a real life context. The teaching boundaries, that is, the conceptual development and learning, are not clearly evident, and the evidence and the collection of multiple assignments allow these studies to fit within Yin's definition of case studies.

Multiple Cases in a Selective High School

The multiple cases consisted of a series of classes in a selective high school and the students' learning that occurred in these classes as well as several grouped interviews. The cases are linked in that the classes and students interviewed were taught or came from a class taught by the researcher in the one school and involved the use and development of analogies within a similar context. Most of the cases were Year 9 classes and involved students studying the unit Active Earth; one case was a Year 7 class studying the unit Electricity and another was Year 8 students followed up from Year 7. A summary of the different classes included in this project is outlined at Table 3.

Table 3: An outline of the path taken by threads of research conducted on analogies and learning showing the class/group and data collected

Step	Class/Year	Process
1	9S1	Evaluation by 9S1 on Chemistry unit
2	9S1	Analogies assignment by 9S1
3	7N	Yearly examination Electricity
4	8N	Follow up Electricity worksheet
5	9S1	Analogies assignment
6	11	Interviews
7	9	Interviews

The Year 9 students were academically able students and highly motivated to succeed and complete all tasks given as part of the assessment program; these students were self-selected into this class that was advertised as a gifted and talented class. The Year 7 students were one class of five unstreamed science classes and the data compare the responses of these students to an open-ended question about analogies in electricity in the yearly examination. An intention of this research was to develop a view of the thinking of high ability students in the science classroom.

METHODS OF DATA COLLECTION

Evaluation of Teaching

In 1996, the researcher established a special timetabled class for students who wished to extend the content covered in the established Year 9 program so that the standard assessment schedule could be varied to incorporate evaluation tasks. The first unit was called Compounds and involved an introduction to the periodic table, the naming of elements and compounds, word and chemical equations, and acids and bases. In this unit, the aim was to link chemistry to the students' out-of-school environment and to include many hands-on experiences. At the conclusion of the first unit for the year, the researcher obtained data from an evaluation questionnaire, which became the starting point for the research project reported in this thesis.

Analogies Assignment

The second data collection occurred during the third unit on geology called Active Earth. This unit was chosen as it was half-way through the course and again allowed the researcher to develop the link between the classroom and the outside world. This assignment was repeated within the case studies during 1997 and 1998 as a means of comparing cohorts of student responses.

Electricity Examination

The Year 7 students in 1996 completed a unit, Electricity, which involved the development of an analogy to explain the separation of energy and the electron in an electric circuit. The yearly examination included several questions about rules for dealing with electricity, circuit symbolism and use of electricity in the home as well as a question about the analogy developed in class. This set of data compared the knowledge retention of content involving analogies and their use in concept development for one class, 7N.

Year 8 Electricity Review

The results of the Year 7 yearly examination showed that several students had modified their analogies to fit an alternative conceptual framework about how electricity flows in a simple circuit. This set of data allowed the researcher to determine the longevity of analogies developed in Year 7 and their subsequent use in concept development of high ability students.

Year 9 Interviews

Several students from the original 7N class were interviewed in 1999 when they were in Year 9. These interviews reintroduced the analogies they developed in Year 7 and explored students' current understanding of electricity. These interviews also explored the use of analogies as a strategy for learning and the way that students learn.

Year 11 Interviews

Five students from Year 9, 1997 were interviewed in 1999, when they were in Year 11, about their understanding of the use of analogy as a tool for learning and their use of analogies since Year 9. This interview also addressed the strategies that these students used to learn in the secondary school.

DATA INTERPRETATION

Methods of data interpretation and development of codes are described in detail in Chapters 4 and 5. These chapters also discuss the theoretical relationships which emerged from the analysis of the data.

RELIABILITY AND VALIDITY OF THE DATA

Trustworthiness

Eisenhart and Howe (1992) define validity as the trustworthiness of inferences drawn from the data that has always been of concern in educational research. Merriam

(1988) believes that all research is concerned with producing valid and reliable knowledge in an ethical manner and this study is no exception. What standards then are to apply to a research project that is embedded in the constructivist paradigm? Guba and Lincoln (1989) identified trustworthiness criteria that take into account the nature of the hermeneutic process within the constructivist paradigm. The criteria of trustworthiness replaces the criteria of internal and external validity used in positivist research (Denzin & Lincoln, 2000; Guba & Lincoln, 1989). Trustworthiness is a term that researchers such as Guba and Lincoln (1989) propose for the overall quality of a piece of non-experimental educational research design. They believe that the essence of trustworthiness is the ability of research to persuade an audience that the findings of a particular enquiry are worth taking note of and that the findings are to be believed and trusted. In order to do this the following additional criteria of credibility must be addressed.

Credibility

Credibility is apparent when the reality constructed by the researcher and attributed to the respondents matches the reality constructed by the respondents. This occurs, according to Bassey (1999), when there has been prolonged engagement with the data sources to build the trust of those who provide the data and the avoidance of misleading ideas. The researcher conducted this research within a specific classroom setting over the period of an academic year. Several assignments had been used in the assessment process and students entering this class had been advised in writing that assessment would involve qualitative assignments, rather than the research assignments, which largely involved cut and paste from monographs or the internet, used in their science assessments in Years 7 and 8. Students were comfortable with the setting and the tasks asked of them.

The design of the study, which used grounded theory, allowed the research to follow and observe emergent issues. The use of the class as the unit of analysis meant that sampling involved responses from most of the students in the class. In the analysis, the emerging data have been systematically checked against the analytical statements, as can be seen in Chapter 4.

Merriam (1988) suggests that long term observation or repeated observations of the same phenomenon increase the validity of the findings. The collection of data from Year 9 occurred over several different Year 9 classes in 1996, 1997 and 1998 and although this has increased the length of the study it does increase the conformability, and so the credibility, of the findings.

Triangulation

This research used qualitative methods of data collection. A criticism of qualitative methods is that they may be subjective and biased. The use of multiple methods or triangulation of methods is one way to overcome these perceived problems and obtain an in-depth understanding of the phenomena being studied. Although the use of triangulation may produce data that are contradictory, holistic understanding of the situation is obtained and the ability of the researcher to construct plausible explanations of the phenomena being studied increases (Cohen et al., 2000).

Triangulation is the display of multiple, refracted realities simultaneously (Denzin & Lincoln, 2000) or more mundanely the use of two or more methods of data collection in the study of some aspect of data collection (Cohen et al., 2000). Credibility of research is strengthened when a variety of sources of data are used to confirm the threads in developing an explanation.

Triangulation has been extended to include time triangulation, space triangulation and methodological replication (Denzin, 1970). Time triangulation was used in this study by collecting data from the same group at different points in the time sequence, for example, correlating data from the yearly examination in Year 7 with responses from the same students in Year 8 and following this with student interviews in Year 9. Time triangulation was also used with the Year 9 students when students from the same cohort were interviewed in Year 11.

Space triangulation occurs when researchers attempt to overcome the problem of studies conducted within one culture or subculture (Cohen et al., 2000). Interviewing students from differing years and so involving different subgroups within the school overcame this problem to some extent.

Methodological replication, as in the repeat of the assignments across several classes, and the use of assignments and interviews, are two examples where triangulation was used to increase the reliability and theory confirmation in this thesis (Denzin, 1970). The type of triangulation used within this thesis is summarised in Table 4.

Table 4: Triangulation of the research methodologies of the thesis

Kind of triangulation	Method of research
Combined	Year 7 examination script
	Year 8 review
	Year 9 interview
Time	Year 7 examination script
	Year 8 reviews
	Year 9 interviews
Space	Year 9 interviews
	Year 11 interviews
Methodological	Year 9 assignments
	Year 11 interviews

ETHICAL ISSUES

The data collected for this project have not been of a highly sensitive nature, politically, socially or physically. Regardless of this, it is important to sustain a concept of respect for all individuals involved (Bassey, 1999) and to obtain students' cooperation and consent to use the information obtained in this research. Confidentiality was considered to be important and in this study students were allocated a series of running numbers as they became involved in the research.

In the construction of the Year 9 class that precipitated the research project, parents and students were informed that data might be collected for research purposes. An outline of the researcher's proposed project was submitted to the school Principal and to the School Council for approval (see Appendix A).

On return of Year 9 assignments, after marking, those students who were comfortable with their assignments being used in a research project resubmitted them to the researcher for copying. In all cases, it was understood that the students' names would not be revealed within the report. The use of the Year 7 yearly examination scripts and Year 8 review was done with the permission of the school Principal, on the understanding that students' names would not be used in the final report.

While conducting the interviews, students were advised in writing of the nature of the interviews and their use in a research project. In all cases, students were advised to take the letter home and discuss their involvement in the project with their parents. If they felt, in retrospect, that they did not wish their interview to be included in the research, they were provided with a phone number and contact address to advise the researcher of their decision. All students interviewed were asked if they objected to a tape recorder being used to record data. A summary of the findings of this research will be sent to the School Council and to the school Principal.

CONCLUSION

An outline of the research process has been outlined in this chapter and a summary is provided. The study was conducted within a constructivist paradigm using a grounded theory and phenomenographical methodologies. The research design comprises multiple case studies using data from Year 7 and Year 9 classrooms as well as follow-up interviews. Chapter 4 analyses the data collected from the Year 7 classroom and Chapter 5 looks at the understandings that emerge from the Year 9 data.

CHAPTER 4

YEAR 9 INVESTIGATION

Alan	*From the moment I walked into this school everyone's been trying to tell me how to do my job… I didn't choose what classes I was going to teach. I didn't decide what sort of classrooms and tables and books and chalk and dusters we were going to use. I'm just the sucker thrown into the lions' den trying to do my best. Trying to do my best for a bunch of kids knowing full well they haven't had a choice either and half of them don't want to be here in the first place.*
Willis	*So what do you want? A democratic staff-student meeting every time we buy new set squares?*
Alan	*Les, unlike you I happen to believe in the potential of every one of those kids. I happen to believe in teaching and if I survive the next few weeks I may even get to like it. But kids don't come here for the teachers' benefit. We're here to help them and if we're not doing that we may as well burn the whole school down. I can't teach kids if I have no idea who they are, what they're like and what they want.*

The fourth year are animals (Tulloch, 1987, p. 43)

Alan, in this quote from Tulloch (1987), enunciates the view that, despite the difficulties of dealing with adolescents in Year 9 [fourth year], education supports student learning and to be effective teachers require a knowledge of individual students in their class, a view which is supported by this research.

Overview

This chapter, the first of two chapters to discuss the results of this thesis, describes the results of the Year 9 investigation which looks at Research Question 1: Can high ability students create their own analogies? and the subsumed Research Questions 1a: What type of analogy do students create?, and 1b: Can students deconstruct their own analogies? The chapter also presents data which is used to answer Research

Question 3: How do analogies help students in concept development? Chapter 5 presents the Year 7 results of the study that evaluated the longevity of analogies in high ability students and the role that analogies play in long-term concept development.

The study within 9S1, a specially created class which operated over 1996, 1997 and 1998, is addressed and presented in this chapter including the interactions which directed the various case studies, the conduct of the initial survey, the subsequent analogies assignment, diary entries and interviews. Also included in the chapter are the coding and analysis of these case studies as well as evidence to support the conclusions that while high ability students are able to identify and produce analogies, most have difficulties when required to map analogies for congruencies and incongruencies. A model of learning of high ability students is presented in which reflection is seen to be a critical component.

Chapter 4 begins by setting the scene for the investigation with the researcher's introduction to the North Sydney Boys High School, the action to change the perception of Year 9 students and the establishment of the special science class 9S1. The results begin with a discussion of the evaluation at the end of the first unit of work that resulted in the development of the analogies assignment. This assignment was set as part of the assessment schedule for the Year 9 unit The Active Earth in 1996 and then set for the subsequent two years, 1997 and 1998. The assignments were coded and analysed and the results are discussed.

Prior to setting the analogies assignment in 1996, students kept a diary for several lessons to record their growing awareness of analogies. The diary entries were coded and the results of the coding discussed. Finally, interviews with several students were also coded and the results of the coding and a discussion of these interviews are presented. The chapter concludes with a summary of the findings from this part of the research.

Setting the Scene

The researcher's experience of teaching at North Sydney Boys High School was that students in Year 9 rejected patterns of assessment with which they were unfamiliar; it proved to be much easier to introduce alternative assignments in Year 7 than in Year 9. In Year 7, everything about high school science is new so students accept assignments looking at the relevance of science, using, for example, portfolio assignments as the normal part of assessment. Year 9 students, unless they have been introduced to alternative assessment strategies early, have an established view of how science education should be conducted and as high academic achievers they have a vested interest in maintenance of established assessment practices. Teacher colleagues also are comfortable with the established system and also are loath to change established teaching practices. One-way that students reject a new system of assessment is to submit very superficial work. Consequently, a different way to change students' perception of what studying science entails within Year 9 was needed.

To create this change in perception in 1996, a special Year 9 class was established called 9S1; all other Year 9 classes were unstreamed. Entry to 9S1 was by application by students or parent recommendation during term four of Year 8. The creation of the class was advertised to all Year 8 students in their science class stating that students in 9S1 would be required to complete the normal sequence of units of study but the science itself would be extended and the assignment schedule would be different. A reason for proceeding in this manner, rather that developing an alternative program, was that while discussing the proposed class formation with the Principal, Bernard Newsom (undocumented interview, 1995), he described other unsuccessful attempts to establish gifted and talented classes at North Sydney Boys High School. Their failure, he believed, was due to the students involved in the class feeling isolated and unable to compare understandings with other students in their year.

Interested students were given an application form or asked to come and see the researcher for further information. In the application students and/or their parents were asked to give reasons why the students should be in the class. The main criterion for entry was an interest and involvement in science rather than high marks in Year 8. On receipt of application forms, a list was made of all students who had applied for the new class. Their involvement in science was ranked, and where there were concerns, the students' applications were discussed with their Year 8 teacher regarding their perceived interest in science over the past year. From this process, a class of 30 students was finally created. Coming from within a selective high school, this class was an academically able, motivated group of students with which to investigate Research Question 1: Can high ability students create their own analogies?

Year 9 followed a program sequence of units including a large chemistry unit entitled Compounds, and three biology units, Human Body Systems, Reproduction and a unit called Disease. The other units were Waves and The Active Earth. All of these units were familiar to the researcher whose strong academic background in the science involved in most of the units allowed extension of the content base of the students.

The unit, Compounds, involved an introduction to the periodic table, naming elements and compounds, word and chemical equations and acids and bases. In this unit the context was the link to the students out-of-school environments and involved many hands-on experiences, including using cabbage indicators and litmus to determine the pH of common household compounds, including foods. Assessment in this unit included the completion of a compounds diary about chemicals, that is, an assignment requiring students to identify one compound from their home, a commentary on the news or newspaper each day for three weeks. To complete the diary requirements, students had to state the name of the compound and where it had been identified. The students were then required to research the literature to find the compound's formula and some of its physical and chemical properties as well as its uses.

At the conclusion of the first unit for the year 1996, the researcher included an evaluation questionnaire that became the starting point for this research. The evaluation focused on three aspects: the level of work being covered in the class, the interest level of the work, and the relationship of the work in class to life outside the classroom. The survey allowed for a free response from the students to comment on any other aspect of the unit. Twenty-six out of the class of thirty students completed and submitted the survey on 19th March, 1996. An examination of the results showed that this was a sufficient number of students to identify student concerns about these teaching issues.

METHODOLOGY

Conduct of Surveys

The surveys were handed out at the beginning of the science class towards the end of the first unit of work for the year, Compounds. This lesson was held in the normal classroom, laboratory three. A science laboratory is not an ideal place to complete a survey, as the position of ten fixed student desks means that some students are well away from the teacher and there is always the risk that some students will discuss answers. On introducing the survey, the researcher discussed the original nature of the class and the need to ascertain whether the expectations of the students were being met. Students were invited to complete the surveys individually and to include their names in order to provide feedback to the researcher. The lesson was quiet and stress free with plenty of time allowed for completion of the survey. While completing the survey the researcher circulated, answered questions and endeavored to avoid student collusion. The surveys were then transcribed, codes were developed, tabulated and summarised.

Code Description

Grounded theory procedures are aimed at identifying, developing and relating concepts (Strauss & Corbin, 1990). The aim of theoretical sampling is to sample events or incidents that are indicative of categories and their properties so that it is possible to conceptually relate to them. By following the methodology of Strauss and Corbin (1990), the data were fully coded initially to establish as many categories as possible. These codes were later condensed to seven primary categories referred to as components of the course: learning, relationship to life outside the course, tone, teacher, teaching level, and time studying, which are defined in Table 5. Within each category a number of secondary key words were identified as outlined in Table 6. The number of times each secondary word is used within each of the seven categories was presented in Table 7.

Table 5: Primary category definitions for the Compounds survey completed by 9S1 students.

Category	Description
Components of the course	The assessment and skill items which were covered in the unit.
Learning	Comments as to the student's learning or understanding.
Relationship to life outside school	Comments as to whether the unit relates to the student's everyday experiences.
Tone	Descriptions of the student's reaction to the classroom, that is competitive, boring.
Teacher	Comments as to the student's perception of the teacher, including her organization, questioning, etc.
Teaching level	How the student found the content covered in the classroom. This includes the perceived depth of treatment, amount of detail, etc. .
Time studying	How much home study was involved in completing the requirements of the unit.

Table 6: Codes used for the 9S1 survey

Category	Secondary key words	Code
Components of the course	Assignments	COMA
	Practical	COMP
	Research skills	COMR
Learning	Learning with understanding	LEUN
Relationship to life outside school	Little relationship	RLLI
	No relationship	RLNO
	Strong relationship	RLST
Tone in the classroom	Boring	TBOR
	Competitive	TCOM
	Interesting	TINT
	Repetitive	TREP
	Same as year 8	TSAM
Teacher	Explanation	TEEX
	Organization	TEOR
	Question	TEQU
Teaching level	Challenging	TECH
	Depth	TLDP
	Detail	TLDT
	Just right	TLJR
	Too easy	TLTE
	Too hard	TLTH
Time studying	As much as Year 8	TSSA
	More than Year 8	TSMO
	Not very much	TSNM
	Too much time	TSTM

Table 7: Compounds survey coded (n=26).

Category	Secondary key words	Code	Number of times used
Components of the course	Assignments	COMA	3
	Practical	COMP	12
	Research skills	COMR	3
Learning	Learning-with-understanding	LEUN	17
Relationship to life outside school	Little relationship	RLLI	3
	No relationship	RLNO	8
	Strong relationship	RLST	16
Tone in the classroom	Boring	TBOR	4
	Competitive	TCOM	1
	Interesting	TINT	22
	Repetitive	TREP	1
	Same as Year 8	TSAM	9
Teacher	Explanation	TEEX	4
	Organisation	TEOR	2
	Questioning	TEQU	1
Teaching level	Challenging	TLCH	4
	Depth	TLDP	2
	Detail	TLDT	2
	Just right	TLJR	15
	Too easy	TLTE	3
Time studying	As much as Year 8	TSSA	11
	More than Year 8	TSMO	7
	Not very much	TSNM	6

The completed surveys were transcribed and are located in Appendix D1. Seventeen students stated (see Table 7) that they were learning with understanding and found the unit interesting. Student 59's response is typical of the group's responses when he stated, "It is very interesting, especially the experimental work, I think I have learnt a lot from it" (059/006); student 60 referred to increased explanation when he described the course as "… similar to the elements course in Year 8 but there is a lot more explanation of why things happen" (060/010).

When asked about the relationship of the unit to life outside school, three students (see Table 7) saw little relationship; for example the comments by student 62 who stated "No, at this stage we don't use these chemical compounds" (062/008). For another student, however, the assignment was pivotal in altering his understanding of chemistry:

> Both my parents and I have commented on how the compound assignment has changed my outlook on science. Sometimes it was a bore finding a compound everyday (especially when I was tired and coming home late), but now I talk to Dad about science and get *New Scientist* when I can. I can instantly recognise compounds in current affairs. (063/112)

Student 63, who like student 65, was one of the 16 who saw a strong relationship to life outside school commented on the several experiments carried out at home on the pH of household chemicals and food: "It is similar in subject and approach to the one I did in Year 8 …but I have never done an experiment at home before" (063/112).

What was of interest to the researcher was that eight students found nothing in the unit related to life outside school, and a further three only found a little related to their life outside school. Typical comments supporting their various views were: "I feel that most does, but some (explanations) are so complicated that it is irrelevant" (065/008); "No, there is not much use for chemistry outside class" (066/008); and "So far, the work doesn't seem to relate to life outside the classroom" (075/008).

The Analogies Assignment

The compartmentalisation of some student's knowledge, typified by the student's responses above, informed the next stage of this project, the analogies assignment. Duit (1990) writes that the advantages of analogies in a constructivist perspective of learning are that they may be able to facilitate change by pointing to similarities in the real world, open new perspectives for the student, they may incite student interest and may encourage the teacher to take the students' prior knowledge into consideration. In this way, analogies may reveal misconceptions in areas already taught.

The Active Earth was chosen as the unit within which to develop an assignment to investigate Research Question 1: Can high ability students create their own analogies? and the subsumed Research Questions 1a: What type of analogy do students create? and 1b: Can students deconstruct their own analogies? This was the second piece of data collection. The unit was chosen as it was mid-way through the course and allowed the author to develop the link between the unit and the world outside her classroom in the teaching. A second reason for choosing this unit was to identify geological analogies. A prior literature search indicated little or no literature on the use of analogies in geological teaching in schools. The analogies assignment was repeated within the case studies in 1997 and 1998 as a means of comparing cohorts of student responses and these became further pieces of data to allow methodological replication.

Analogies are believed to help student learning by providing visualisation of abstract concepts, by helping compare similarities of the students real world with the new concepts and by increasing motivation (Duit, 1991). The class was introduced overtly to the use of analogies in science and to the use of the FAR guide, a three-phase approach to analogy teaching developed by Treagust, Harrison and Venville (1998) involving Focus-Action-Reflection. The guide is used to focus on the target concept, to then map the features of the analog and the target and determine where the analogy breaks down and finally to reflect on the clarity and usefulness of the analog and consider ways in which the analog and the mapping may be improved. The main ideas of this guide are listed in Figure 1.

Focus	*Concept*:	Is it difficult, unfamiliar or abstract?
	Students:	What ideas do the students already have about the concept?
	Analog:	Is it something the students are familiar with?
Action	*Likes*:	Discuss the features of the analog and the science concept. Draw similarities between them.
	Unlike:	Discuss where the analog is unlike the science concept.
Reflection	*Outcome*:	Was the analog clear and useful or confusing?
	Improvements:	Refocus as above and in light of outcomes.

Figure 1: The three aspects of the FAR guide for the teaching and learning with analogies. (Treagust et al., 1998)

Several analogies used in previous units were discussed and analysed from the FAR perspective and the students were then presented with an assessment task based on this perspective. The first part of the assignment asked the students to identify and analyse analogies in textual material; the second part required the students to create and analyse their own analogies in the light of the weaknesses identified. The assignment was issued about halfway through the five to six week teaching sequence and students had two weeks to submit their work. The assessment specifically asked students to: a) identify three analogies used to help explain concepts in the unit The Active Earth, b) identify the strengths and weaknesses of these analogies, and c) discuss the effectiveness of these analogies in developing geological understandings. The assignments were collected, assessed and then returned to students. Those who agreed to allow their assignments to be used for this research, resubmitted them so they could be copied and coded.

Suitability of the Assignment

The use of the assignment as a tool for obtaining information is not ideal as the assignment required long responses in several sections from students, some of whom found this intimidating to begin with. On each occasion that the assignment was used, class time was spent reviewing the requirements and this was repeated at least once during the two-week period allowed for its completion. However, the assignment required an extended response to individual parts and a few students missed an entire part of the assignment.

Processing of the Assignments

Each student was allocated an individual number code ranging from 001 to 108 as he became part of this thesis. Each line in the assignments from 1996, 1997 and 1998 was numbered with a running four-digit number, starting from 0001. The assignments were then read and comments written by students described by single word descriptors such as 'onion', 'analogy', 'superposition' which were listed alongside the line where this term or concept appeared. After a period of time, the number of times each descriptor appeared was analysed and many descriptors became subsumed into categories that became the main themes to emerge from the data. Each category was given a code constructed as a four-letter symbol, where, for example, ANAI indicates that a student was able to record an analogy. The data were then analysed using these categories. Where a category was identified in the student's writing it was recorded with the four letter code for the category, as well as a three digit code for the student and a four digit line code. For example ANAI/093/0005 identifies that student 93 had at line 5 of the assignments identified an analogy. All information was then locatable and retrievable. The four letter, seven digit codes were entered into a spreadsheet together with any researcher's comments and examples of student comments highlighting a particular category. These data were then sorted to enable evidence to support the categories to emerge. Two assignments, transcribed in full are located in Appendix D2.

The six primary categories - analogy identified, limitations, own analogy, own analogy extended, visualisation and concept development - used to code the assignments are shown in Table 8.

Table 8: Primary category definitions and codes used for the analogy assignment for the unit Active Earth completed by 9S1 students in 1996, 1997 and 1998

Category	Definition	Code
Analogy identified	The student was able to record an analogy	ANAI
Limitations	The student was able to identify at least one area where the analog and target did not correspond	ANLI
Own analogy	The student was able to create his own analogy	ANAO
Own analogy extended	The student was able to identify the limitations of his created analogy and developed his original analogy	ANEX
Visualisation	The student referred to visual imagery in his discussion	ANVI
Concept development	The student described how the analogy supported concept development	ANCD

An example of the secondary words used to derive categories with the category, 'visualisation' is shown in Table 9. These categories were totalled within years and graphed.

Table 9: Secondary words used to derive the category visualisation

Category	Secondary words		
Visualisation	Drawing	Irregular pattern	Scale
	Compare	Not complicated	Similar
	Differences	Not simple	Size difference
	Domestic	Phenomena	Squeezing
	Formed	Picture	Thin
	Harder	Properties	Visual description
	Identify	Ratio	Visualise
	Infer	Resemble	

RESULTS AND DISCUSSION

The number of times that each category was coded for each of the years when the analogy assignment was used is presented in Table 10. These tabulated data are also presented in graphical form in Figure 2. It is immediately apparent from the graphs that there is a difference in the data between 1996 and the following two years, 1997 and 1998. The total number of analogies identified in the assignment increased from 32 in 1996 to 67 and 59 in 1997 and 1998, respectively. The same order of difference is seen in the coding for Limitations, 29 in 1996 increasing to 75 in 1997 and while lower in 1998 at 54, was almost double that coded in the 1996 assignments.

Table 10: Number of times each category was coded for in the analogies assignment for the unit Active Earth in 1996, 1997 and 1998

Category	1996	1997	1998
Analogy identified	32	67	59
Limitations	29	75	54
Own analogy	12	29	25
Analogy extended	6	14	12
Visualisation	13	25	27
Concept development	9	38	28

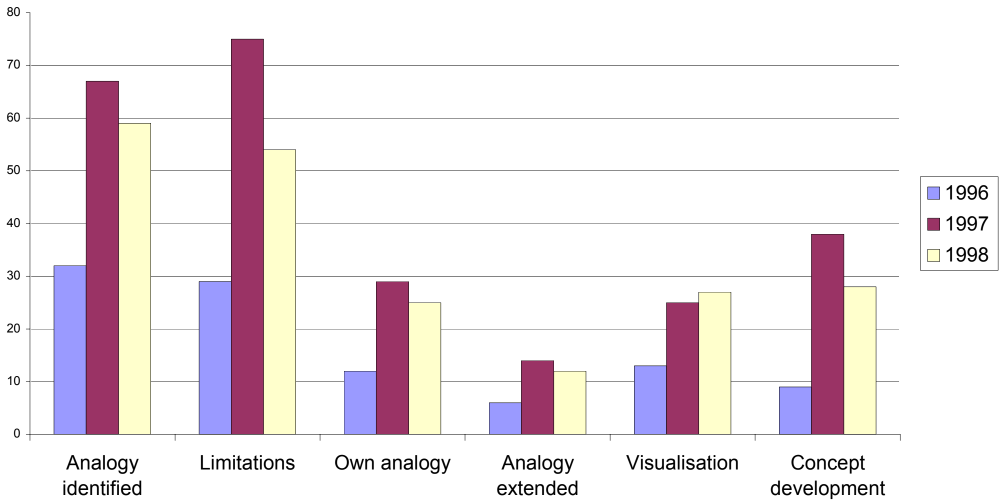

Figure 2: Comparison of analogies assignment for the unit Active Earth using the codes for 1996, 1997 and 1998.

Possible Reasons for the Variability in Data

The variability in the data could be due to a number of reasons. Each class group is a new cohort of students who bring their learning perceptions from previous experiences to new situations. Although all students in these classes have similar high ability, the effect of changing the perception of what is required in science assessments may have had a significant impact on the involvement of Year 9 students with their assignment preparation. The researcher began teaching at this selective school in 1995 when Year 9 classes were streamed. Yearly reports included a ranking of students in the year group, that is, students were given a rank out of 150. In 1996, this procedure was changed, streaming of students was stopped, students were ranked on their position in their science class, and a special class based on student and/or parent nomination was established. The first class in this new, motivated and interested group, 9S1, had experienced science to this point under the pre-existing regime when in Years 7 and 8. While they were aware that entry into this new class meant a different type of assessment schedule, dealing with the actuality of these new assignments was very difficult for students to accept.

The following year, the 1997 Year 9 group had been in Year 7 in 1995, the year the researcher started in the school. Part of the researcher's teaching allocation that year was a Year 7 class, which was presented with a variety of non-traditional assessments, including portfolio assessment. As well, the researcher introduced a hands-on unit called Forces and a unit Electricity, each informed by constructivist notions of learning. While the researcher only taught one Year 7 class, the alternative units were taught across the year, and included a Year 7 excursion to the Powerhouse Museum to support the Forces unit with parent helpers. Several phone calls from parents commented positively on the assessment schedule and the formation of 9S1. These actions support the researcher's view that assessment within her home class was widely discussed within sections of the school community. The 1997 and the 1998 cohorts would have had similar introductions to high school. While the researcher has had little input into Year 8 class content and organisation, the abandoning of streaming of Year 9 meant that the pressure to avoid a lower streamed class did not exist if students were amongst the lower students as a result of their marks in Year 8.

A second reason for the variability in data may be uncertainty of the researcher in dealing with what in effect are a group of highly capable, motivated and enthusiastic boys. This uncertainty, which provided the impetus for the development of the survey discussed earlier in this chapter, may have been conveyed to the students who felt insecure in their ability to prepare the analogies assignment. Increased confidence in introducing analogies, and increasing the students' awareness of analogies prior to writing the assignment, may be part of the reason for the increased coding in various categories in 1997 and 1998. This increased awareness was evident in an exercise undertaken in the 9S1 class in 1997 when students were asked to comment on their awareness of the use of analogies at the end of the chemistry unit. These comments show that many students were unaware of the use of analogies in science or in other subjects for that matter. Student 31 stated that his experience with analogies was quite limited as he had only used or seen them in his school science class (personal communication, 1997) and student 40 said that the use of an analogy to explain the discrepancy of adding 50 mL of water to 50 mL of methylated spirits was the first time he had recognised what an analogy was (personal communication, 1997).

A third reason for the variation in coding of categories may be variability in intake of students in the Year 6 Entrance Examinations, or variability of students requesting to enter the especially created Year 9 class.

CAN HIGH ABILITY STUDENTS IDENTIFY ANALOGIES?

In the analogies assignment, students were asked to identify three different analogies from geology and students took their analogies from a range of sources that are identified and tabulated in Table 11.

Limitations

Although most students completed this section of the assignment and were able to identify analogies, the part of the assignment that asked them to identify where the analog was congruent or incongruent with the target was the least well answered. Many students produced responses which indicated little understanding of what was required and this can be seen in the following responses: "I can see no real bad points with this analogy" and "I can't find much wrong with this analogy either" (049/6190 and (049/192); "Apart from this weakness, there seemed to be no other weaknesses to this particular analogy" (053/6559); "There are no weaknesses I am aware of with this analogy (plasticine rock layers) (046/6075); and "I can't find much wrong with this analogy either" (049/6192). These responses by Year 9 students support work by Grosslight, Unger, Jay and Smith (1991) who found that students view their models (in this case analogies) as physical copies of reality and do not see the model (analogy) as being designed for a particular purpose, that is to help communication. Grosslight et al. (1991) recommended that students have more experience with models and their role in the service of scientific inquiry.

Table 11: Source of analogies and examples used in the Year 9 analogies assignment

Source of analogy	Example
Text book (Heffernan & Learmonth, 1987)	"The plates are like giant pieces of a jigsaw puzzle that don't quite fit together". (093/0003) "It compares the crust of the earth to an eggshell, where the inner yolk is the core and the egg white is the mantle". (075/4053)
Practical activities described in the text book (Heffernan & Learmonth, 1987)	"Plasticine which can be moulded and shaped to produce folds and faults in rocks". (048/6104)
Videos	"A map of the earth is divided into tectonic plates. Then they are laid on a tray, which is filled with a mixture of peanut butter and red food dye (magma). Pin holes are made under all the major volcanoes so that when, for example, the Pacific Plate is pushed underneath Japan, the pinhole at Mount Fuji will overflow with lava". (036/5090) "In a video that was seen in class, the tectonic plates were compared to sections of crust floating and moving in tomato sauce and peanut butter mantle". "In another video the movement of tectonic plates was compared to fingernail growth". (039/5323)
Hands on activities	"The use of block models in the study of the cross section was employed to give a three-dimensional aspect of what a real cross section looks like". (053/6514)
Demonstrations	"the twisting that occurs in a shear fault can be explained quickly with a piece of chalk. By turning it from either end it splits and the lines where the pressure was applied can be clearly seen". (059/2307)
Memory enhancement	"The final analogy that I chose was a simple one that helped me to distinguish and remember the difference between an anticline and a syncline. It just linked an image in my head to the concept that I was trying to learn. I simply remember that an ant climbs up a hill to link to the word anticline, and therefore an anticline is shaped like a hill". (038/5260) "An ant climbs up a hill and then link it to the fact that anticline begins with the word ant". (038/5240)
Teacher talk	"Convection currents are like boiling soup and bread crusts".[10] "The second analogy I have to offer is comparing dinner plates to tectonic plates". (071/2250)
Other sources	"Pretend the water from your garden hose is a river, let the water spatter and trickle on the dirt in your back yard. You will see it knock bits of dirt away to make tiny gullies. Real rivers do the same thing" (063/4263), from the *Child craft- the how and why library*). "Sediments have apparently formed on the earth ever since water, wind and ice began to erode the landscape in one way or another. The result may be likened to a book with the strata corresponding to the leaves" (100/0789), quotes from *Biological Science: The Web of Life,* 1968).

Sometimes, limitations in the students' understanding of the explanation in text reduced the effectiveness of an analogy. For example, an analogy in the class text-book, *World of science* (Heffernan & Learmonth, 1987), described the mantle as "solid but like ice, it can move. Ice in glaciers is quite solid, but glaciers flow to the sea; they do not just slip down" (p. 245). This lack of understanding caused enough anxiety in one student for him to complain that:

> If, like me, you do not know how ice flows, then this analogy is fairly useless. I would at least have liked an explanation of how ice flows included in this analogy. The analogy did not allow me to understand any new ideas, but may have if I hadn't understood the phenomenon already. (034/4947-4949)

Unshared attributes between the analog and the target are often a cause of misunderstanding for learners who attempt to map unshared attributes from the analog to the science concept (Treagust et al., 1998). Although students appeared to have little difficulty in identifying analogies, the second step of students being unable to analyse the similarities and dissimilarities of the analog and the science concept is of concern because it may lead to alternative conceptions being developed. This area of analogical analysis requires further work to ascertain how difficult it is for new learners to map incongruencies of the target and analog. The superficial mapping of the analogy to ascertain the unlike characteristics of the analog to the science concept indicates either that students lacked perception to identify where the analogy breaks down or they did not see the significance of this step in the assignment.

CONCEPT DEVELOPMENT

Analogies were seen by many students as aids to concept development which supports the comment by Duit (1990) that "analogies may be valuable tools, especially in conceptual change learning, because they may open new perspectives" (p.1). Several students commented on the role of the analogy in supporting their conceptual learning, as illustrated by the following two examples:

> This analogy was very effective in allowing me to understand the proportion of the crust to the rest of the earth, even though I cannot imagine something fifteen times thinner than an egg shell. It helped me because of its simplicity (033/4859).

> …This is the most effective analogy for the studying of the earth's structure [the swede or turnip analogy for the earth's structure in Heffernan & Learmonth, 1987, fig. 7.74]. This analogy helped me study for the topic test on the unit. After Jack told me about this picture, it made it clearer to remember. This analogy together with the text from the book has helped me understand that different layers have different contents, features and thickness. (050/6302)

ANALOGIES AND CONCEPTUAL CHANGE

The results of this assignment support the findings of Wong (1993) who found that analogies can stimulate new inferences and insights, and those of Brown (1992) who observed the ability of analogies to support and help bridge conceptual change. The effectiveness of an analogy is heightened by its position in the learning sequence; for example, one can almost hear the disappointment in this student's response in not finding an analogy earlier, when he says:

> ...we had already done a fair amount of work on folds and faults before I came across this analogy so it was not much use to me. If we had used it earlier, I may have learned the work faster because the model is easier to understand than cross sections. (099/1472-1478)

This disappointment is compared with another student who was able to use an analogy and reduce the intellectual effort in bridging conceptual change. "Without this analogy, learning these things would have been much slower" (037/5175). Student 33 described his increased scientific understanding gained using analogies, commenting upon his changed conception using an alternate science conception, common amongst young children, to heighten the explanation of the clarification in his thinking: "It gives an accurate perception of just how thin the crust really is in a clear, easy to understand way. (Oh well I guess that puts off my plan to dig to China!)." (033/4825)

The ability of an analogy to help students to resolve conceptual conflict is seen in the following response from a student who felt insecure about asking questions which exposed his lack of knowledge. This scenario was a problem for some students in this class where entry presupposed a high level of knowledge. One such student wrote:

> For many days, I had been wanting to ask, but I never got around to it, so when I finally found the answer, thanks to the analogy that I could refer to, a great load was taken off my mind. (99/1484)

Within the conceptual change view of learning and understanding, Strike and Posner (1985) refer to the role of current conceptions in generating new knowledge. Here was a student reflecting on the tension of being caught between the intellectual expectations generated by his previous conception and his move to a new conception, hindered by classroom dynamics. His relief was quite palpable. Analogies as used within the classroom and as part of this assignment were seen to resolve this conceptual conflict for some students and supported conceptual change.

ANALOGIES AND VISUALISATION

Amongst the advantages discussed by Duit (1990) in the use of analogies to engender conceptual change was visualisation. This aspect of the analogy was seen to be significant in the Year 9 assignment when students discussed the impact of analogies on their concept development. Comments about visualisation were so numerous that they were included as a separate category in the coding. Students remarked that the analog looked similar to the target: "This model is very effective indeed, as mentioned above, because the model looks so much like the real thing, that is, the folds in the rock in the continent" (041/5772).

Several students commented on the way that analogies supported their learning style, as illustrated by the following quotes: "When I can see and feel it, I can visualise and understand better about new ideas" (050/6337), and

> Once I had a picture of what Pangea looked like, it was not very difficult to memorise the theories behind it. Somehow, interactions with visual aids stimulated brain activity, and I felt it was much more effective than just listening to a generous lecture or video explaining the same topic. (039/5318)

CAN STUDENTS CREATE THEIR OWN ANALOGIES?

Many students were able to devise analogies for themselves which involved a deal of creative and intuitive thought, but others presented analogies which had been presented in class as their own or were only able to create analogies very similar to those presented in class. The assignment was a difficult exercise for many students, as they could not simply retrieve information from the literature. For a few students, the analogies presented did not relate at all to the unit being studied.

Some students appeared to use the model ascribed to Wallas (Dreistadt, 1969). In this model, there are four stages to creative thought – preparation, incubation, illumination and verification – each of which are illustrated in student 32's description of the process of creating his own analogy when his father was trying to explain about salt invasion:

> After I eventually got an idea of what it was about, I started to develop an analogy in my mind. The idea was to use an everyday thought process to explain a complicated phenomenon like salt invasion. Picture a large bucket with a lid with holes in it on top. In each of these holes, there are straws attached to kid's mouths. Near the top of the bucket there is a tube which has been fed through a hole in the side of the bucket. Through this tube, there is a constant flow of coke into the bucket. The level of coke stays the same as long as kids keep sucking out through the straws. (032/4789)

In this illustration, the preparation stage was the discussion with his father, the incubation phase was his thinking about it, the illumination phase was when the student "… got an idea", and the verification phase was his preparation of the assignment and uses of this new concept to support his new conception. This process is glimpsed when another student "…automatically sensed that it corresponded" (099/1433).

The analogies developed by Year 9 can be grouped according to a number of criteria, but all give an insight into the conceptual change process. Using the four-phase model of Wallas (Dreistadt, 1969) the classroom interaction was the first or preparation phase, this was the phase where students gained data and systematically and consciously analysed the new information; the incubation phase was when the students' reviewed the assignment's requirements, when they mulled it over while doing other things; the creation of the analogy occurred in the illumination phase, while the writing of the assignment was in the verification phase.

The mulling over during the incubation phase can be likened to meditation which is defined in the Macquarie Dictionary (Delbridge et al., 1991) as the act of thinking deeply or as described in the Encyclopaedia Britannica (2001) [Electronic version] as a private mental exercise consisting of any innumerable techniques of concentration, contemplation and abstraction. Some techniques used in meditation include clearing the mind of all extraneous thought for a period of time by chanting a mantra, repeating a number or just counting sheep. This process allows thoughts from deep within the mind to surface and new ideas to emerge. The act of washing one's face or brushing teeth can be thought to be similar to meditation because they are processes where all other thoughts are banished, and for some students they were places where it appears the illumination phase occurred. The relationship of the concept to teeth, pimples, food and drink supported the idea that these relate to processes where illumination occurs. For other students, remembering that this is a boys' school where there is an active Industrial Arts department, the reflective and subsequent illumination phase may occur while sanding or sawing wood; these are repetitive activities that require little mental activity but do require concentration on a single task, similar to the repetition of a mantra in meditation, as can be seen in the grouping below where many analogies developed related to activities where contemplation may occur, such as repetitive activities involving body maintenance.

Body Parts

Several students used visual analogies relating volcanoes to the pimples on their faces, while others used tessellated knuckles (040/6329), fingerprints (087/0290), teeth and tooth decay (039/5495).

Process

Some students focused on physical processes. Student 89 used the convection currents in the Earth's mantle as the concept and magnets in a pool as the analog (089/0522) while two other students used weathering as their concepts and their analogs were sanding a piece of wood (093/0070) and rubbing a coin on sandstone brick (088/0378).

Own Experience

The use of soft drink cans exploding and the cooking of eggs and soup as analogies related to periods when the students were involved in mealtimes, when intellectual processing was not a priority. This contemplation on food allowed the illumination phase to occur.

Analogies Very Similar to Those Given in Class

Analogs very similar to those given in class were those using the layers of a sponge cake, a chicken egg, egg shell, soccer ball, cricket ball and a piece of paper. The use of these analogies indicated a lack of confidence by the students that may be either in their understanding of the content covered in the classroom or in their ability to construct an analogy without being able to confirm their answer. The fact that these students produced analogies that were different from the classroom or textbook examples supports the researcher's contention that the students understood what was required of them.

Unrelated Analogies

Two students presented analogies unrelated to the topic, The Active Earth, such as relating a body to a computer, and the other RAM (random access memory) to a computer. In these two cases, however, the researcher believed that the students were actively involved in the conceptualisation of analogies and did not stop and review the question on the assignment sheet. In the researcher's experience, the submission of assignments which are to the most part unrelated to the topic are not uncommon. For example, student 33 when asked in Year 7 to research a notable scientist and discuss the impact of their work produced a map showing Columbus' discoveries.

ANALOGIES DIARY

After reviewing the analogies assignment in 1996, a decision was made to heighten students' awareness of analogies earlier in the course. During the first unit, Compounds, students were asked to keep a diary of analogies used in the unit and to comment on the effect on their concept development. Diaries were mentioned as a tool in the PEEL Project (Baird & Mitchell, 1986) but the authors found that their use was of limited value because it was not completed in lesson time. Consequently, the aim within the unit, Compounds, was to use lesson time to complete the diaries. Unfortunately, this proved more difficult than originally envisaged and the entries lapsed after only a few days. Nevertheless, the students' comments are enlightening in that they demonstrate a heightened awareness of analogies and, for some students, an awareness of the role of language in structuring their scientific knowledge.

Twenty-five students' diary entries were transcribed and are located in Appendix D3. The entries were coded using the same codes for the analogies assignment, with only three categories being used in this coding exercise, as shown in Table 12. Students were at first unsure of what was required in making the diary entries so were instructed to think of those analogies that had been used in the unit so far and to think about whether or not these had helped in their understanding of the work which had been covered. On average, each student was able to describe at least three analogies used. The analogy that appeared to have made the most impact was one devised by the researcher to explain addition of volumes. This activity uses the Predict, Observe, Explain model outlined in Baird and Mitchell (1986) in order to encourage discussion early in the unit. In this activity, students are asked to measure out 50 mL of water and 50 mL of methylated spirits and predict the result of adding these two liquids together. The predictions were then written on the board. After this phase, the students added the liquids together and recorded the result. The last part of the activity was the explanation phase.

Table 12: Results of coding Year 9 diary entries, 1997 (n=25)

Category	Number of times counted
Analogy identified	77
Concept development	26
Visualisation	12

This activity allowed the students to go beyond their learned answers and delve into and verbalise their conceptions of the particulate nature of matter. Many students had difficulty with the researcher's final explanation of atoms, the concept of 'empty' space and the size of atoms, as their conceptual models did not fit this new observation. In an effort to resolve this problem, the researcher devised an analogous situation for the next lesson involving 50 mL of sand being added to 50 mL of 'hundreds of thousands', that is, tiny coloured balls used to decorate icing on cakes. Students were asked to predict the resultant volume if these two substances were added together. The visual nature and conceptual conflict which preceded this lesson ensured its place in most students' memories. A more detailed example is student 43's quoted below:

> A science analogy is showing you something you know and comparing it with something you are not sure about, e.g., showing 100's and 1000's with sand and how the sand particles are smaller and fit between the hundreds and thousands. This is compared with methylated spirits and water and how the metho particles are smaller than the water and when you add them, e.g. 50 mL and 50 mL you would get about 97 mL and not 100 mL. (043/0129-0138)

Other analogies that students included in their diary entries were those to explain the development of the model of the atom. Analogies included an atom is like a golf ball, the plum pudding model of the atom, modelling the location of the students at their desks in the laboratory (where desks are bolted to the floor in set rows) to represent electrons in shells, the golf ball-football stadium-car park analogy of the amount of space in a atom, the 'if an atom was the size of a marshmallow' analogy presented by the researcher to help students conceptualise the size and number of atoms, atomic model kits to construct compounds, and jigsaw cut outs of atoms to form compounds and write formulas. This list of student generated analogies supports the researcher's premise on which her research questions were based, that is when made cognisant of the constructed nature of science, students are able to identify analogies. The diary entries also support the contention of Glynn (1991) when he described the processing of related concepts by analogies as being a basic part of human thinking. Nearly all students referred to the ability of analogies to effect conceptual change, for example student 55, who found this topic very difficult, described how he came to understand ionic bonding when he wrote: "I had a vague idea that this was the way it worked, but this confirmed what I thought" (055/077). Many students referred to the visual nature of analogies in supporting their conceptual understanding. Student 51's comment is typical: "The use of this model increased my understanding of naming compounds because it visualised how compounds are joined" (051/0192).

However, analogies are not always as effective as the teacher or textbook author intends and may lead to confusion (Thiele & Treagust, 1991). Indeed, the ability of an analogy to assist in conceptual development was not always the case; some students found an analogous activity did not help but rather increased their uncertainty. For example, student 34 commented that "The jigsaw model was a bit confusing because some compounds you could not make" (034/0009).

Student 46, who went on to become one of the 20 students selected for the Australian Olympiad Summer School when in Year 11 in 1998, had already developed a sophisticated understanding of compounds in Year 8 and commented, "the use of models did not increase my understanding of naming compounds. It didn't help me because I already knew from last year [in Year 8] when we did a chemistry unit" (046/0051). This comment was repeated by student 43, when he stated that "…the use of the model didn't really increase my understanding because I kind of knew how to name compounds, but naming the compounds from the models was easier than looking up the valences" (043/0139). The advantage of the analogous work within the classroom supports the verification (Dreistadt, 1969) of the new concepts. In other words, putting a difficult concept aside for a period of time makes it easier for the correct concepts to develop. In student 43's case, putting aside the work on naming compounds begun in Year 8 made it easier for him to understand the analogous work on compounds in Year 9.

FOLLOW-UP INTERVIEWS

In November 1999, two students from the 9S1 class in 1987 and four students from the 9S1 class in 1998 were interviewed to determine whether they believed the work on analogies completed while in Year 9 had any effect on their ability to conceptualise understandings in later years of high school.

The interviews were conducted individually in the office of the Head Teacher, Administration, while she was absent. Each interview was audiotaped and the interviewer took no additional notes. Overall, the interviews went smoothly and a good rapport existed between the interviewer and the students. Half an hour was allotted for each interview and this was enough time to complete the list of questions prepared by the researcher and upon which the interview was structured. After transcription, the interviews were analysed and four primary categories about learning were identified - analogies, assignment, learning and science learning. Definitions of these four categories are presented in Table 13 and the categories, secondary words and an occurrence summary within each category are tabulated in Table 14. The inclusion of the secondary words provides a greater context for discussion. Three of these transcribed interviews for students 93, 101 and 104 are included in Appendix D4.

Table 13: Primary category definitions for the Year 10 and Year 11 student interviews

Category	Description
Analogy	Comments relating to the use of analogies in the teaching/learning process
Assignment	Comments about the analogies assignment given in Year 9
Learning	Comments that refer to the strategies that the student uses to actively learn material.
Science learning	Comments about interest and learning science

Table 14: Categories, secondary words and total number of times each secondary word was coded for Year 10 and Year 11 interviews (n=6)

Category	Code	Secondary Word	Code	Total
Analogy	AN	Analog	AN	4
	AN	Analogies identified	AI	15
	AN	Concept development	CD	12
	AN	Discussed with others	DI	3
	AN	Everyday life	EV	4
	AN	Mapping	MA	1
	AN	Visual	VI	4
Assignment	AS	Level	LE	3
		Thinking involved	TH	4
Learning	LE	Application	AP	1
	LE	Basics	BA	1
	LE	Hands on	HO	2
	LE	Interest	IN	10
	LE	Make notes	NO	1
	LE	Memorise	ME	3
	LE	Practice	PR	1
	LE	Reading over	RO	3
	LE	Remembering	RM	16
	LE	Revision	RV	1
	LE	Similarities	SI	4
	LE	Simple concepts	SC	4
	LE	Understanding	UN	7
	LE	Visual	VI	1
Science learning	SC	Interest	IN	1
	SC	Special lesson	LE	3

Analogies

Students were asked whether they remembered the analogies that they had developed for the analogies assignment in Year 9. Some students could not comment initially but when prompted were able to recreate one or more analogies. Of greater interest to the researcher was the students' clear recollections of their thinking and what they were doing when they developed their analogy. For example, student 93's response (when in Year 10) is typical when describing the analogy he created in Year 9:

> I was just talking to Student 100 a few days earlier, and I think I had a woodwork assignment at the time. When we were sanding down a piece of wood bit by bit, particles of the wood came off slowly as sawdust and I sanded it down until it got smaller and smaller and I changed the shape altogether which was similar to the patterns of erosion caused by wind or water. (093/025)

More than 12 months after writing the assignment, student 93 remembered not only the analogy but also the moment when the analogy was created, while he was sanding wood. This response answers Research Question 1: Can high ability students create their own analogies? Student 93's response supports the researcher's thesis that for conceptual change to occur students need to incorporate reflection time and that conceptual learning requires effort. Indeed, several students mentioned the challenging nature of the analogies assignment and the effort required to develop their own analogies. Student 100's comments especially reflects this aspect of the assignment; when asked if he found the exercise difficult at the time, he stated:

> Difficult, not difficult, just I had to work, I had to think and it was challenging at the time. It wasn't an easy assignment where you could sit down and do it off the top of your head. It actually did take quite a bit of effort into coming up with that (the analogies). (100/0323)

Another student recalled that it took him "ages to think of an analogy" and after he had he "discussed it with someone else in class and what they were doing and that was the best I could come up with" (104/070 – 074). These students' comments are relevant because they mention the importance of discussion with another person to clarify their ideas, a comment often repeated by other students. The need to verbalise and test their changing conceptual frameworks is important to learners as they bridge their conceptual change (Wood, Cobb, & Yackel, 1995).

Anxiety

Many students mentioned that not being able to complete an assignment by locating the appropriate information from the World Wide Web or from a reference book created a deal of anxiety. Early in his interview student 100 recounted his feelings, "… I can remember sitting at my computer and being really agitated trying to think up something". On being asked if he had discussed his anxiety with anyone at home, student 104 responded:

> My mum. I was trying to think of something and she was saying 'What are we doing at the moment?' and I said we were doing volcanoes and she was saying, 'Okay what's a volcano like'? So basically she talked it through with

> me. I was thinking, OK what else has pressure inside? I'm thinking through a kettle, a pot of water is much more similar to a volcano. She didn't actually do the assignment but was someone to bounce ideas off. (100/0302 - 0309)

This period of anxiety is part of the reflective process during which students have to expend effort to alter an existing conceptual framework and incorporate new patterns of thinking (Scott, Asoko, & Driver, 1998).

Learning Strategies

When questioning students about their memories of the analogies that they had developed for the Year 9 analogies assignment, the researcher asked about strategies that these students use to learn in the school setting. Student 101's answer is typical:

> I find that if I concentrate and work through things I can learn long lists and bits of information, …you sit down and you read it then you think about it and then you read it again. (101/091)

On hearing and reading these comments, the researcher was originally concerned that these high ability students had few learning strategies and questioned why, on the surface, these able, successful students appeared to have no learning strategies. However, if the reading of notes is seen as part of a reflection process and if this is interpreted, not as rote learning but part of an active learning cycle where gifted students are able to interact with the written material and reflect on their understandings, then this is a productive process and needs to be interpreted as such in this group of students. This process appears to be the same reflective process referred to in the writing of the analogies assignment as outlined by Wallis (cited in Dreistadt, 1969). Upon contemplation of his learning, student 38 referred to short cuts he used, but when asked specifically about science learning, he implied that it was a matter of learning discrete facts and that no strategies were employed to link or relate the information. One of the short cuts was "when you memorise stuff to songs so it keeps it in your head…", (38/0064 - 0071) and in science this student stated that "I just run over everything and memorise each thing, just in a basic straight forward way". (38/070 - 074)

High ability students are effective processors of information (Cropley, 1993a). What was originally seen as a paucity of learning strategies, just reading over notes as a learning strategy, is then seen as an integral part of the learning process of high ability students. The analogies assignment, the analogies focus in 9S1 science, and some support work in languages to learn vocabulary lists, seemed to enable students to reflect and incorporate learning into either existing strategies or to recreate previous conceptual strategies.

Several students commented that their learning involved linking information to what happens in the day. The success of practical work could be that it is highly motivating and so involves heightened brain activity. When students reflect on their day's activities, those activities which resulted in greatest successful expenditure of mental effort and of greatest motivational involvement are those in which greatest reflection will occur. Eventually, the greatest chance of conceptual change will be for the concepts involved in these processes as illustrated by the following interaction with student 93.

One of the questions asked students to remember a science lesson where they thought 'Oh gosh'. Student 93 remembered a practical demonstration and responded:

> I suppose whenever you do an experiment, it makes life a lot easier because it's not remembering something from the textbook, you're actually seeing it in action. So when we were studying complete combustion, you had, I suppose, examples on display where you showed incomplete combustion, complete combustion. You saw the different chemicals, you saw how they reacted, because of the fire, because of the noise. It just made it a lot easier to remember what happens to different types of combustion. (093/0163-0173

The researcher went on to ask why this sort of lesson was so effective and student 93 explained that he was able to link the learning to a variation in the experimental class activity:

> Probably the lesson is different, that it stands out because you did an experiment, you did an activity, you didn't take notes or watch a video. It's

> probably more likely to stick in your mind. Then if you remember loosely that day you are more likely to remember what happens in it and so in the test you think oh I remember what we did that day, or I remember how that works. (093/0178-0185)

In delving further, the interviewer asked about things which students felt would be remembered in the long term. Student 93 commented on the importance of the new, humorous and strange in triggering memory, but then referred to the different points of view presented in the Year 10 unit, Evolution. This unit aims to view evolution from a scientific evidence viewpoint, looking at changing viewpoints and how the theory developed out of evidence. This unit challenged many students' view of the constancy of science and created interest as typified by student 93's response:

> Okay I enjoy electricity but probably everything I've learned this year will have gone out of my head. Like in Evolution, which I didn't enjoy as much, when you looked at some of the different theories for dinosaur extinction, the thing with the eggs, when we saw the different ways that people see evolution and the religious debates. While it wasn't my favourite topic, I just found that very interesting, everyone's different point of view and I'm much more likely to remember that five years from now. (093/0192-0202)

Student 40's comment that things that interest him are easiest to learn was typical of the students' responses. "I remember things which interest me… I sort of like how equations are worked out, I didn't like geology that much so I can't remember all the terms and stuff but I remember the biology, that's quite interesting" (040/0085). Students enter any interactions with existing likes and dislikes and this affects the way they interact with the information presented. It is no different in the science classroom. If students are interested in the topic being covered, their level of interaction with the information presented is enhanced, there is a greater chance that they will engage with the information, reflect on what was presented and talk about it with their peers and family. There is therefore a much greater chance for learning and conceptual change to occur. Conceptual learning is not a passive process and learners have to expend energy if conceptual change and deep understanding are to occur. For high ability students, like all other students, this process requires mental engagement and reflection and learning will occur more frequently if the student has an interest in the material being covered. Motivational strategies to involve less interested students are then seen to be an important part of the lesson sequence if learning across a range of students with different abilities and learning styles is to occur (Gardner, 1998).

CONCLUSIONS

This chapter supports the premise underlying this thesis that high ability students are able to identify analogies from textual material, from videos and from classroom discussion. This identification continues into other contexts and over time. This chapter provides evidence to answer Research Question 1: Can high ability students create their own analogies? High ability students are able to create their own analogies, and this process is able to support deep learning of information. The evidence presented in this chapter also allows the researcher to provide answers to Research Questions 1a: What type of analogies do students create? and Research Question 2b: Can students deconstruct their own analogies? High ability students do not appear, from the activities reported on, to be able to map the congruencies and incongruencies between the target and analog when analysing analogies, although this inability may be due to insufficient practice at developing this skill.

The chapter also provides evidence to answer Research Question 2: What role do analogies play in learning? and Research Question 3: How do analogies help students in concept development? but these questions are the major focus of Chapter 5. Analogies are specifically able to support the learning style of students who prefer visualisation of information. From these case studies in the Year 9 classroom, development of student analogies appear to support the learning of students by linking to a model of learning which involved preparation, incubation, illumination and verification as presented by Wallas (cited in Dreistadt, 1969). The information to be learned is presented to students and for there to be conceptual change students need to engage mentally with the information. This engagement may be due to an interesting presentation, to results which conflict with the student's existing conceptual framework, to hands-on experiences, or to a novel association of ideas. Student developed analogies encourage high ability students to engage with the new material. Talk is important, and class discussion that enables students to voice their perceptions and understandings allows student understandings to be challenged. The development of a product, an analogy, alerts students to concepts that need to be fitted within their existing conceptual frameworks and challenges the student to alter their framework to fit the new information.

Analogies support reflection and the analogies assignment allowed students to reflect on their understandings. The chapter presents evidence that for high ability students the process of reading over notes was also a process of reflection. Associated with the reflective process is the need to talk on a one-to-one basis with a trusted other person. In this chapter, the analogies assignment allowed interaction with peers or adults, such as parents. These exchanges allowed new ideas to be explored and tested in a safe, non-threatening environment. The last process that appears to be part of the process is verification, where the analogies exercise allowed students to test their new frameworks in novel situations.

In the next chapter, the results of case studies involving Year 7 students are presented to provide further evidence for Research Question 2: What role do analogies play in learning? and the associated subsidiary questions, 2a: What type of analogies are the most effective for supporting conceptual change in students?, 2b: How long do analogies created in the classroom remain with high ability students? and 2c: If students revert to an alternative analogy, what happens to the original classroom analogy?

CHAPTER 5

EXPLORING YEAR 7 DATA: ANALOGIES AND ELECTRICITY

Then said a teacher, Speak to us of Teaching …

And he said:

No man can reveal to you aught but that which already lies half asleep in the dawning of your knowledge.
The teacher who walks in the shadow of the temple, amongst his followers, gives not his wisdom but rather of his faith and lovingness.
If he is indeed wise he does not bid you enter the house of his wisdom, but rather leads you to the threshold of your own mind.
The astronomer may speak to you of his understanding of space, but he cannot give you his understanding.
The musician may sing to you of the rhythm, which is in all space, but he cannot give you the ear, which attests the rhythm, nor the voice that echoes it.
And he who is versed in the science of numbers can tell of the regions of weights and measure, but he cannot conduct you thither.
For the vision of one man lends not its wings to another man.
And even as each one stands alone in God's knowledge, so must each one of you be alone in his knowledge of God and in his understanding of the earth.

From The Prophet by Kahlil Gibran (Gibran, 1956, p. 67)

Gibran was a favoured poet amongst those looking for a more thoughtful, less mechanistic voice the 1970's. It was reassuring to find that his views on education are still current, and his philosophy could still speak to the researcher as the data from the Year 7 work on electricity were analysed. He could even be reinterpreted as a constructivist.

OVERVIEW

A unit on electricity informed by constructivism was taught in Year 7 and included models to explain the movement of electricity in a simple circuit and the development of an analogy to support the accepted scientific view of this movement. This information was tested in the Year 7 yearly examination. The results of the examination indicated that several students had changed their conceptual framework. These data were collected to answer Research Question 2: What role do analogies play in learning? and the subsumed questions 2a: What type of analogies are the most effective for supporting conceptual change in students? 2b: How long do analogies created in the classroom remain with high ability students?, and 2c: If students revert to an alternative analogy, what happens to the original classroom developed analogy? Data in this chapter also provide responses to Research Question 3: How do analogies help students in concept development? This chapter firstly examines the results of the yearly examination and a subsequent retest of the same material in Year 8. Six interviews with Year 9 students – students from the original Year 7 class – who review conceptual ideas about electricity flow in a simple circuit was designed to ascertain whether the concepts attained in Year 8 have remained stable and whether their memories of analogies have been retained as a tool to assist learning. The chapter concludes with a discussion of the model of learning developed in Chapter 4.

INTRODUCTION

Research Question 2 and its subsumed questions arose after marking students' answers in the electricity section of the Year 7 yearly examination in 1997. The examination asked students to describe their understanding of electricity, an understanding that had been developed and challenged in the teaching of the Electricity unit. While no students in the class agreed with the scientific view of electricity at the beginning of the unit, all students were in agreement at the end of the teaching sequence. However, the researcher observed that a number of students had reverted to the non-scientific, alternative conception held prior to the teaching of the unit when answering the examination question. To determine if this reversion continued over time, the students were asked the same set of questions under test conditions early in term one of Year 8. Research Question 2c arose as a result of interviewing several students about their understanding of electricity at the end of 1999, when the students were in Year 9. From this information, the researcher discusses the use of analogies in developing conceptions, and the role of analogies in developing conceptions of high ability students.

BACKGROUND TO THE ELECTRICITY UNIT

For the past decade, there has been much research into alternative conceptions held by students and teachers about electric current in simple circuits (Osborne, 1981; Stocklmayer & Treagust, 1993). The topic of electricity is one where students bring to their lessons perceptions and understandings embedded in their real life experiences. All students from a western society have lived among electrical appliances since they were born and so bring to the classroom a well established view of electrical functioning which often differs from that of the scientist (Stocklmayer & Treagust, 1993). A number of strategies have been developed to bring these positions closer together and Osborne (1983) and Cosgrove (1995) crystallized four mental models from young peoples' explanations of a circuit consisting of a globe connected by two wires to a cell. These mental models are:

- A unipolar model in which electricity is considered to travel by a single wire to a light and none returns; the role of the second wire being unspecified (model A).
- A clashing current model in which different forms of electricity pass from each end of the cell, come together and are consumed in the bulb (model B).
- A circulating but not conserved model (model C), and
- A circulating but conserved model (model D).

Model D is the model referred to as the scientific or scientists' model.

In surveys of students' understanding of electric current in a circuit (Osborne, 1983), most students identified models B or C; few students identified models A or D as best fitting their ideas. In further classroom studies these models were elucidated and challenged using two ammeters, one located on either side of the light. On finding that the readings on the ammeters were identical, many students were puzzled. Some asked, for example, if the battery would go flat, and others seemed to be convinced by the test and then reverted to their original ideas. Others acknowledged the likely value of model D to scientists while still preferring their own ideas (Osborne & Freyberg, 1985).

The teaching of a topic such as electricity in high school always causes some concern as it contains difficult concepts. At a previous school in which the researcher taught, the topic was not in the curriculum until late in Year 10. Cosgrove (1995) discussed the advantages of placing a topic such as electricity later in the curriculum and using algorithmic manipulation, such as with Ohm's rule, to enhance understanding, but then went on to recommend the introduction of the topic earlier with a conceptual rather than an algorithmic foundation. In a study in a Year 9 classroom, 30 students were familiarised with electric circuits and then challenged with the four models characterised by Osborne (1983). In this study, the students planned and tested their models using two ammeters, one on either side of the bulb in a simple circuit consisting of a bulb and cell joined by two wires. After this testing, 25 of the 30 students agreed that model D was the best answer. The last stage of the study involved the development of an analogy to explain electric current and the result obtained with the ammeters. This student-developed analogy was refined over three lessons and allowed the students to differentiate electrical flow into two components, the material which flows in the wires and the force which pushes it.

Upon becoming familiar with the literature on conceptual change and the study by Cosgrove (1995), the researcher developed a Year 7 teaching unit on electricity based on the findings described above.

YEAR 7 ELECTRICITY UNIT

The researcher-developed unit was taught over a five-week period, divided into several phases, namely familiarization, challenge, analogy and problem solving. For the familiarisation phase, students constructed many different circuits using simplified non-commercially produced sets of electrical equipment that were hand-made, using pieces of copper sheeting attached to wooden blocks with all connections between cell, bulb and metal being overt. This arrangement allowed connections to be easily observed.

After about four lessons of constructing circuits in the familiarisation phase, there was a challenging phase where students were presented with Osborne's (1983) four models and asked to vote for the model that agreed with their concept of how electricity moved in a simple circuit. At no stage through the sequence of lessons was the scientifically accepted model of electricity presented as such. No student voted for model D, the scientifically accepted model; most voted for model C, the circulating but unconserved model, with a few students voting for model B and no students voting for model A. These results are consistent with the Cosgrove (1995) study.

As in the Cosgrove (1995) study, students were asked to test their models scientifically using ammeters. This was done using the POE teaching approach (Baird & Mitchell, 1986), where P strands for predict, O for observe and E for explain. The prediction involved a thought experiment with a simple circuit and student prediction of the result of ammeters in the circuit depending on their model of electricity. For example, if model A was believed to be the correct model then there would be a reading on the ammeter between the battery and the bulb but no reading on the ammeter between the bulb and battery. If model B was the students' favoured model, then the reading would be the same on both ammeters but the deflection of the meters would be opposite to each other. Subsequently, these predictions were written on the board. The circuit was then constructed with ammeters on either side of the bulb and the circuit completed; the readings on both ammeters were observed to be identical, the prediction for model D. A great deal of student discussion ensued and led into the last phase, working with the students to develop an analogy to explain the observations. Like the Osborne (1983) study, students developed their model as a result of teacher-led prompting and role-playing. The bottom line for the role-play development was that it had to explain the same reading on the ammeters, the light glowing, and the eventual running down of the battery.

Many proposals were put forward and eventually a role-play was developed and played out. In the student-developed analogy, students became electrons and held a piece of paper, representing energy. Two students formed a gate, representing the battery, at the front end of the laboratory, and two others formed a gate at the back to represent the bulb. The rest of the class lined up in single file in a circle around the room, moving to pass through the two gates. At the battery, there was a box of paper (energy) and as the students moved through the gate they were given a piece of paper. At the bulb students gave up their paper as they moved through the gate. This analogy allowed the ammeters to count electrons (students moving past) to see that they were the same on either side of the bulb. The battery going flat and the bulb glowing in this analogy became a function of the energy (paper pieces) transferred via the electrons from the battery to the bulb. After role-playing the analogy, the students wrote a description of the role-play in their notebooks.

Following the role-play, the students were again presented with the four models — A, B, C and D — and asked to vote on the model which they now believed represented their view of electricity in a simple circuit. All students voted for model D.

The last part of the electricity unit comprised solving problems of several more complex circuits in class and an assignment which involved choosing one of a group of several circuit problems to construct at home. As part of this assignment, students were also required to prepare a circuit diagram which was presented and described to the class.

The unit was assessed formally in a paper and pencil format as part of the yearly examination. This examination contained questions about students' understanding of electricity, safety and the use of fuses, students' ability to recognise open and closed circuits and students' views about electrical flow. In the question about electrical flow, students were presented with the same simple circuit used in the familiarisation and challenging phases of the unit. In this circuit, two ammeters and a switch were added. An ammeter was located on either side of the bulb, and underneath was the question: 'Compare the readings on the two ammeters in the above circuit with a closed switch'? The examination scripts for the researcher's class were transcribed (see Appendix D5) and then coded.

After transcription, each line in the script was numbered and each student given a separate number. The scripts were coded using six categories - ammeter, reason, analogy, language, circuit 1, electrical safety and fuse (see Table 15). Codes were determined by the Year 7 yearly examination questions and the subsequent Year 8 review task, as well as the student responses. For example, one question asked whether there was a reading on the ammeter or not, with most answers coded under the category Ammeter. The students were then asked to give a reason for their response and these were coded under Reason. If a student mentioned an analogy, then this was coded under the category Analogy; if there was no further description, the response was coded AANA. If an actual analogy was described then it was coded as, for example, a coal train or a paper analogy. In their answers to this question, several students used terms such as current, amps, power and voltage in ways that indicated a high level of understanding and these have been coded as Language. In one question, students were asked to determine whether a circuit was open or closed; these responses were coded as Circuit 1. The last two categories relate to a question where a person was standing in a pool of water with a drill and students were asked to identify several safety features that were being ignored. If a student answered this question, it was coded as awareness of safety issues. The last question related to the use of a fuse in a household appliance and was categorised as Fuse.

Table 15: Codes based on the Year 7 yearly examination and Year 8 review task

Category	Student response	Code
Ammeter	Ammeter 1 has a higher reading	MHRE
	No reading on the ammeter	MNON
	Ammeters both read the same	MSAM
	Cannot determine an answer	MUND
Reason	Electrons on both sides of the battery	RELE
	Energy was used up	RENE
	Cannot determine an answer	RUND
	Refers to earlier work	RLAY
	Uses an alternative reason	RALT
Analogy	An analogy was referred to	AANA
	Coal train analogy	ACOA
	Paper analogy	APAA
	Own analogy	AOWN
	Electricity Model B	AMOB
	Electricity Model C	AMOC
	Electricity Model D	AMOD
Language	Use of term “current”	VCUR
	Use of the term “power”	VPOW
	Use of the term “amps”	VAMP
	Use of the term “voltage”	VVOL
Circuit 1	Lights on	CLIO
	Lights not on	CLNO
Electrical safety	Aware of safety issues	ESAF
Fuse	Wire melts	FWIM

Year 7 Students’ Responses to the Electricity Unit

Each piece of coding included the code, the student number and the line number, so that responses could be located. The responses from the Year 7 examination, are totalled and summarised in Table 16.

Table 16: Summary of student responses from the Year 7 examination (n=26)

	Student responses		
	Correct response	Incorrect response	No response
Students’ understanding of safety	25	0	1
Recognition of an open circuit	24	2	0
Student able to describe the function of a fuse	25	0	1
Student able to predict the reading of two ammeters in a closed circuit	18	7	1
Students’ reasons for the reading on the ammeters being the scientists’ conception*	6	12	8

* If a student’s reason was included in the answer to the prediction of the reading on the two ammeters, or the Reason section of the paper then it was included in these figures.

Students' Understanding of Safety

The question about safety incorporated a diagram of a person using a drill in an unsafe manner and students had to identify safety issues. Twenty-five students, over 96%, correctly answered this question and one student left the question blank (see Table 16). A typical response by the students was that by student 7 who covered the main points when he wrote "Never use an electrical appliance near water and always wear rubber soled shoes" (ESAF/007/0135).

The overwhelmingly positive responses from the class in reply to the question associated with danger can perhaps be explained as being part of the common culture of knowing which these students bring with them to school (Solomon, Black, Oldham, & Stuart, 1985). In this study, Solomon et al. make the point that students have lived amongst electrical appliances for as long as they had been alive. In a later study, these authors looked at the perception of danger associated with electricity amongst students and emphasised that, in the home, there is constant verbal reinforcement of the dangers of electricity (Solomon, Oldham, Black, and Stuart, 1986). All students interviewed by Oldham, Black, Solomon, & Stuart (1986) stated that they operated light switches and plugged in appliances, but parental admonishments continually emphasised the need for caution when dealing with electricity and punishments for misuse were not uncommon.

Fuses

Twenty-five of the students were able to correctly describe the use of fuses in electrical appliances (see Table 16). Only one student left the answer blank. Typical of the responses was student 13 who stated that fuses were used: "So that if the wire overheats the very thin wire will melt and stop the circuit, so nothing can happen"(13/239). Student 14 provided a full answer to the question stating:

> Toasters and other electrical appliances include fuses in their circuit, because if there was a power surge they would be damaged by excess current, but with fuses, if too much current tries to enter the circuit, the fuse will melt creating an open circuit to protect the appliance. (14/265)

Students again overwhelmingly showed an understanding of the function of items in a circuit. This question involved a straightforward concept that was reinforced by the observation of a fuse wire, a fuse from a house, the demonstration of rewiring a house fuse, stories about times when people used fencing wire instead of fuse wire to rewire a house fuse, and the safety problems that this could cause. However, the high proportion of students providing the correct response to this question cannot be fully explained by previous knowledge but by the fact this was material was applicable and easily able to be learned by a group of high ability students.

When interviewed two years after the Year 7 examination, in November 1999, student 15 was asked what sort of things he remembered best in science, and stated:

> …the things that hit me that I think I will remember forever; even though I got confused in the electricity work in Year 7, it helped me in a lot of ways to understand how things work, like a fuse. I'll never forget thinking 'Oh, so that's why those lights go out….' (015/129)

Student 15 showed that the science taught in the classroom in Year 7 was being applied to help make sense of his world outside the classroom and assisted in providing a link to the more difficult conceptual work presented later.

Open and Closed Circuits

At the completion of the unit on electricity, all students were able to predict the reading of two ammeters on either side of a cell in a simple, closed circuit, wired in series with a light. In the Year 7 yearly examination, students were presented with two diagrams, one a realistic diagram of an open circuit wired in parallel and the other a symbolic diagram of a series circuit that included a battery bulb and ammeters set up as described above. Twenty-four students, over 92% (see Table 16), were able to correctly identify from the realistic diagram that the circuit was open and therefore unable to conduct electricity; these students also identified the use of a parallel circuit in a home. A typical answer by student 7 stated that: "It is designed so that you can have two switches (e.g., one upstairs and one down stairs so you only need to switch one on or off" (07/236).

A few students, however, had answers which were unclear; for example, student 22 knew that the realistic circuit will allow a current to flow if it is closed but it is unclear from his answer if he knew whether the circuit in the examination paper is open or closed. He stated:

> Pat and Rob have made the switches with metal paper clips and metal drawing pins which will work fine. The electricity will flow all the way around because it is all wired up correctly depending if the switches are closed. (022/352)

This student's answer was unable to be coded as a closed circuit.

Seven students, or 26% (see Table 16) of the class, reverted to an alternative conception of electric current in the yearly examination, about two months after the unit had been taught, and were unable to correctly identify the ammeters as reading the same in a simple electrical circuit. When asked for the reason for their answers, these students typically stated:

> They should not be the same because the circuit should not have an even number of electrons going through the circuit. One should be less, and one should be more (003/045)

> The two ammeter readings would not be the same if the circuit was working. This is because the electricity would go around left, across the switch and a bit would be used up if it went through the light. This would be the other way round if the circuit was running the other way. (005/092)

Three of the students' answers indicated that they had moved to model C, as the answer above, and now believed that electricity was being used up in the circuit. One student referred to an unspecified model, two others made no mention of a model or analogy in their answer and the seventh left the answer blank. Most of the class (18 students or 69%) stated that the two readings would be the same (see Table 16). From this response it would appear that eight students had reverted to their earlier conception of electricity. This is consistent with findings of Cosgrove and

Osborne (1985) where they described how children seem to change their views immediately following a lesson but that there was a certain amount of regression towards intuitive ideas over a period of time.

Models of Electricity

After students were asked to predict the reading of two ammeters and then explain their answers, the responses were coded and tabulated (see Table 17). Fourteen students either directly referred to the models or analogies presented in class or indirectly to an analogy; a further ten students answered the question with no reference to a model or an analogy. Several students left the answer blank.

Table 17: Answers to questions about models (n=26)

Examination question: Explain your answer above using a scientifically accepted model of electricity that you developed in class		
Types of responses		Total responses
Analogy referred to		14
	Non specific analogy	2
	Coal train analogy	2
	Paper analogy	2
	Own analogy	0
	Model A	0
	Model B	1
	Model C	4
	Model D	3
No analogy referred to		10
No answer		5

Note: One student did not answer either part of this question and some students explained their answer in another question. These responses have been included in this table and so responses total more than 26.

Subsequently, to gain greater insight, the explanations of those students who predicted the ammeters would be the same were compared with those students who predicted that the readings would be different (see Table 18). Of the students who answered that the ammeter readings would be the same, seven or 27% of these students did not include an explanation or an analogy to support their answer and of those students who did describe an analogy, one described model B, which is not a scientifically accepted explanation for electricity flow and another two described an analogy which could not be coded. One student who correctly answered the question about the ammeter left the second part of the question blank. These students were most likely either answering the prediction part of the question intuitively, having forgotten the material from the class, reverted to their original conception, or while reverting to an original conception were in a state of transition and unaware of, and unable to remember the models and reasoning which occurred in class. Only nine or 35% of the group were able to support their answer with an explanation, which was similar to an analogy developed in class. Seven students had reverted to an alternative conception. Of these three did not refer to an analogy or did not answer the question and another four referred to model C.

Table 18: Comparison of explanations to readings on ammeters (n=26)

Examination question: Explain your answer above using a scientifically accepted model of electricity that you developed in class			
		Ammeter reading the same (n = 18)	Ammeter reading different (n= 7)
Analogy	Non specific analogy	2	0
	Coal train analogy	2	0
	Paper analogy	2	0
	Own analogy	0	0
	Model B	1	0
	Model C	0	4
	Model D	3	0
No analogy		7	3
No answer		1	0

Note : One student did not answer this question.

Students who predicted that the ammeter readings would not be the same

Of the students who answered the ammeter question incorrectly, two students gave reasons that did not refer to an analogy. Student 2 stated the reason that the readings were not the same was because "electricity has to go through the resistor which slows the current down" (02/035). While not referring to an analogy, this answer can, in hindsight, be seen to relate to the role-play conducted in the classroom. As an aside the researcher can remember discussing the function of a resistor (as the light) in a circuit to the movement of students around the room. It appears that student 2 had focused on this and incorrectly mapped the analogy to the concept.

Student 11 also stated that the reading on one ammeter would be higher than the other: "Ammeters measure amps which is the amount of energy in an electron" (11/207). This student was aware that the concept of energy and electrons have to separate to develop the scientists' model but had linked energy to his definition of amps and this results in an explanation that "energy has been used up in the bulb and the first ammeter still has amps in the circuit but the second one didn't" (11/209), an incorrect response. Here is evidence of a student in transition who only needs a little support work to completely move his conceptual understanding.

All students who answered the question incorrectly and included reference to an analogy referred to model C. Student 3 stated: " This is true [the ammeters do not have the same reading] because if the ammeters were the same then the battery would not run out, whereas if the model I think is the correct one the battery will eventually run out" (03/049).

Students who predicted that the ammeter readings would be the same

Eighteen students, nearly 70% of the class, stated correctly that the ammeter readings would be the same on either side of the cell. Eight students referred to analogies in their explanations. Of the eight students using an analogy to answer this question, two used the coal truck analogy; for example student 1 wrote: "… think of electrons flowing through wires as coal trucks carrying energy. When it reaches the light it lights up and the coal trucks keep moving back to the cell for more energy" (01/016). The second student referred to a class exercise when he stated: "In class we used the analogy of the coal trucks (amps) carrying coal (volts) to be burnt by the globe. The number of trucks stayed the same but the number [amount] of coal differed"(17/277). Two students described the actual paper exercise in their answer, typified by student 13 who stated:

> Electric current is not used up by the globe, the voltage is, e.g. if you had one person for the globe and one person for the battery and the battery had a piece

of paper the rest of the people were electrons. If the battery gave little pieces of paper as the people walked by and then gave it to the globe, the battery would soon run out. (013/0245)

While student 26 used the paper analogy to derive the correct prediction for the ammeter readings, his answer included some misconceptions, when he stated:

> Pieces of paper were passed from person to person (people being the wire) into the beam balance where the weight was measured (ammeter) and the paper was passed through a little hole where the amount was accumulating to create light. Then the paper was measured on the beam balance and then returned to the paper storage. (026/0481)

Student 26 mapped the people as being the wire rather than electrons in the wire, and so his people remained stationary and passed the paper along the wire. He also had the paper being weighed at the ammeters, which meant that he had not separated the concept of electron and energy or force, using the ammeter as an electron counter. Student 26 also had energy being "returned to the paper storage", that is, the energy was retained within the system. Even though student 26 had used the paper analogy to derive the correct answer, his mapping of the concept to the analog was not the same as that done in class and will likely cause him confusion in future concept development.

Student 14 referred directly to the models discussed in class in his answer. His explanation was very clear and shows that he comprehended the separation of energy and electrons and the role of the ammeter in the circuit:

> My explanation is using model D and that the same amount of current goes in and out of the globe. This would not explain though, why a battery goes flat. Well it does, although the current is the same the amount of energy it is carrying is not, as it goes to the bulb it has a lot of energy, as it comes out it doesn't have as much energy. Which explains why the readings are the same. (014/275 - 282)

Student 24 described model B, a model that no one voted for in the class activities, in answer to the prediction of ammeter reading stating, "The ammeter readings would be the same amount of amps, and going in the same direction towards the light bulb. That is according to one of the models discussed in class" (024/433). In the second part of the question he reasoned that, "In class we developed a model that electricity flows to the battery through both leads at the same amount of amps. This explains why the battery runs out and it was proved possible with an ammeter" (024/437). In the "clashing current" view of electricity described by this student, electricity leaves both ends of the cell, clashes and is destroyed in the light and heat is created in the bulb. Student 24 has reverted to a model which fits what he remembered of the demonstration with the ammeters where the readings were the same. However, he cannot correlate this observation with the scientists' model, model D, so he used model B, which now fits his conception. Student 24 appears to have moved from model C or model B prior to testing, to model D at the end of the unit, to Model B after the end of the course. The researcher cannot be sure of student 24's original view as this was collected as the result of class voting and individual results were not determined.

Seven of the students who answered the ammeter question correctly did not use an analogy in their answer; some however used descriptions that appeared to be not far removed from the support of the analogy. Typical of this sort of answer is student 10's response, "The ammeter counts particles (amps) so each particle is carrying a store of energy which means that when they get to the lights something happens and that is they give their energy to the light and go back to the battery" (010/0186 – 0190). Student 17 also has dropped all references to the class work when he explained that the reading on the two ammeters will be the same because the "…number of volts differ. The current going to the ammeter remains the same" (017/0281).

Other student answers were unclear, and it was impossible to determine these students' understanding; for example, student 12 stated, "When electricity is flowing around a circuit the speed and the amount should be the same" (012/0227-0228).

SUMMARY OF THE YEAR 7 RESPONSES

The students' responses in the Year 7 examination showed a range of conceptions. Several students had reverted to their prior or another alternative conception but the majority of the group maintained the scientific view of electric current which had been developed in class and these students were able to correctly predict the readings of two ammeters in a simple circuit. Some of the students who were unable to correctly predict the readings of the two ammeters appeared from their reasons to be in a transient stage and their conception of electric current appeared to be unstable. One of the students who correctly predicted the readings of the ammeters used an alternative conceptual framework. Of the students who were able to predict the readings of the two ammeters, most referred to an analogy or model in their response, and those who did not refer to an analogy or model had explanations that could be attributed to the role-play carried out as part of the class work. These results indicate the power of the analogy to support conceptual change as indicated by Cosgrove (1995). From their explanations, a few students showed that they had incorrectly mapped the concept and the analog and this was causing problems in their understanding of the target concept. A few other students explained the reasons for their prediction of the ammeter readings with a scientifically sophisticated answer that made no reference to specific class work.

THE YEAR 8 RETEST

At the end of the electricity unit in Year 7, all students explained their understanding of electric current flowing in a simple circuit using the scientists' model. By the examination at the end of the year, about 27% had reverted to their original, earlier model or had moved to another alternative conception to explain the flow of electric current in a closed circuit. From the students' answers, it appeared that several were unsure of their understanding. To determine whether the change in conceptual understanding continued with time, Year 8 students were administered with that part of the Year 7 examination which dealt with circuits together with Questions 3(a) and 3(b). This retest was administered towards the end the end of term 1, about five months after the students had sat the Year 7 examination, and about seven months after the teaching of the unit on electricity.

Year 8 groupings were different to Year 7 classes and it was decided after consultation with the Principal, and with the cooperation of Year 8 teachers, to administer the quiz across the whole of Year 8. To maintain continuity of students, only those in the researcher's Year 7 class were included in this analysis. Prior to the retest, students were informed that the researcher was interested in comparing their answers with those from Year 7 and that the retest was not part of the assessment schedule. Students cooperated and the retest was completed at the beginning of a normal science class with students sitting in normal test mode, that is in silence, with one student at either end of the bench and one in the middle. There was no antagonism associated with the administration of this quiz.

The results for the retest questions were transcribed and coded using the codes developed for the Year 7 examination. The transcribed and coded results are included at Appendix D6, and are summarized and tabulated in Table 19.

Table 19: Year 8 comparison of explanation of ammeter results (n=23)

Examination question: Explain your answer above using a scientifically accepted model of electricity that you developed in class			
		Ammeter reading the same (n = 1)	Ammeter reading different (n= 6)
Analogy	Non specific analogy	1	0
	Coal train analogy	0	0
	Paper analogy	2	0
	Own analogy	1	0
	Model B	2	0
	Model C	0	0
	Model D	1	0
No analogy		9	3
No answer		1	3

Note : One response was unable to be coded.

Twenty three students were retested, three less than the number used for analysis of the Year 7 yearly examination. These three students were absent or had left the school. The researcher decided to exclude the student's scripts if their results had not been included in the Year 7 examination previously to allow a direct comparison of Year 8 conceptions with those in Year 7.

In the retest, 17 students, or 74% of the 23 students stated that the two ammeters would read the same and seven or 26% stated that the readings would not be the same (see Table 19). One student's response could not be determined and was included with those who did not think the ammeter results would be the same. Two of the three students not included in the retest, in the Year 7 yearly examination had stated that the readings on the ammeters would be the same and one that the readings would be different. This result compares closely with the 70% who stated the readings would be the same in Year 7, and close to 27% who stated that the results would not be the same.

On first view, it appears that there has been little change in the students' answers; however five students, over 21%, changed their answer since the yearly examination in Year 7. Two of these students moved from stating that the ammeter readings would be the same when asked in Year 7, to the ammeters being different in Year 8; three students stated that one of the ammeter readings would be higher when in Year 7 and then changed this to state they would be the same in the Year 8 retest. Students changing their prediction on ammeter readings and the direction of the change are shown in Table 20.

Table 20: Students changing their predictions on ammeter readings

Student number	Year student made prediction	
	Year 7	Year 8
002	Different	Same
003	Different	Same
004	Same	Different
009	Same	Different
011	Different	Same

On reviewing the papers of the students who changed their prediction of the readings on the ammeters, one, student 9, had an identical explanation to another student, student 8 in the Year 7 examination. No other student gave this explanation, that is, “Even the most accurate ammeters in the world will measure the same” (008/0144). Student 8 maintained his view that the ammeter readings will be the same in the Year 8 retest, stating that “the ammeters will have the same reading because not even the most powerful ammeter in the world could tell the difference” (008/0068). Student 9 changed his answer and stated that “the first ammeter will have a more higher reading than the second ammeter (crossed out, the same reading)” (009/0073). This student then stated that:

> Electrons are pushed by a force or volt and run through the ammeters. The ammeters read how many electrons are running through. The electrons then run into the light. After this they run back into the battery going through the ammeter. (009/077-083).

From this explanation, the researcher would have expected student 9 to say that the ammeter readings would be the same and it appears that this student has not reverted to an earlier conception but is in a state of transition. In Year 7, he may have copied student 8’s answer, perhaps because he was still unsure of his conceptual understanding. Student 9’s explanation in Year 8 confirms that he has separated the concept of electron and energy and will most likely not revert to an earlier conception. His response in Year 8 does not appear to be a clear-cut change to an alternative conception.

The second student to change his prediction from the same reading to a different reading was student 4 who stated in the Year 7 examination that “The reading of the two ammeters should be exactly the same” (004/0069). Student 4 did not give an explanation for his answer and this may be because he knew or he guessed the answer. If he guessed, it may have been intuitive or from remembering from the class work. In the Year 8 retest, student 4 appeared to have moved to an alternative conception when he stated that “The ammeter on the left will have a higher reading while the one on the right will be lower” (/004/0058). In his explanation, he referred to the Year 7 work, “We made one like the one above last year” (004/065) which supports the view that he may have remembered the work from Year 7 when answering the Year 7 examination paper. Student 4 was the only student to clearly revert to an alternative conception in the Year 8 retest. This student had family problems during Year 7 and Year 8 and it was unlikely that he would have reviewed his work out of class at any time during this period. He would not have allowed himself reflection time to consider the conceptual framework under discussion as other issues were of a more pressing nature at the time.

Three students, students 2, 3 and 11, have moved from an alternative conception to the scientists' conception in the same period. Student 2's explanation in Year 7 stated that the "electricity has to go through the resistor which slows the current down" (002/0035). In the Year 8 retest, student 2 used an analogy as his explanation describing how "Everyone in the class walked around the room with a piece of paper" (002/0184). The analogy has supported this student's ability to problem solve and correctly answer the question, even though he did not use it in the Year 7 examination, the role-play has been remembered and used several months after the activity was performed.

In Year 7, student 3 referred to the models needed to explain the "flattening of a battery" and chose an answer in line with Model C. In Year 8, he stated that the reason is that this explanation "refers to model number 4" (003/0160), the scientists' explanation.

Student 11 was the third student to move from an alternative conception to the scientific view. In discussing his previous answer the researcher stated that it appeared that an incorrect definition had affected his problem solving. In Year 8, with no definitions learnt for the retest, student 11 stated "When the circuit is closed electrons go through to the light and the electrons keep passing through" (011/0005). This student had, as predicted from his Year 7 answer, moved over time to problem solve using the scientist's conception.

Over a five-month period, almost 21% of students changed their answer when asked to predict the reading on the two ammeters placed in an electric circuit. Of these, only one could be clearly said to have moved from a scientist's view of electric current to an alternative conception. Three moved from an alternative conception to a scientist's view; one of these was supported by the use of an analogy derived from a class exercise in Year 7. However, when the researcher reviewed the reasons given for the ammeter readings two students appeared to be using an alternative conception of electrical current flow in Year 8. One student, student 22, when asked his reasons just stated, “It is model B” (022/0123). As he included no more explanation, it is difficult to know if he is referring to the “clashing current” model of electrical current or has put down the wrong letter consequently the researcher placed him in an uncertain category. Student 24, however, stated that “The difference between the two readings of the ammeters is the same amount of electricity, but one reading is from the left and one from the right” (024/0113). Student 24 was consistent in his view as he gave a similar explanation in Year 7.

Where students gave the scientifically acceptable answer in Year 7 and again in Year 8, many students’ answers are very precise in Year 8. Several who had described in detail the analogy referring to coal trucks in Year 7 have omitted any reference to analogies in the Year 8 explanations. For example, student 1 described the coal truck analogy in the Year 7 examination, and in the Year 8 retest his explanation makes no reference to this. He stated:

> The readings on both the ammeters will be the same because ammeters measure the flow of electrons in the circuit. The scientific model that was developed [showed] that the electrons move through the circuit and the energy gets used in the light when the electrons move back to the battery. (001/0008)

This answer is sophisticated for a Year 8 student. Student 1 was able to identify that his answer was not a “black and white” response. In his answer the use of the phrase “the scientific model that was developed” indicates an awareness that his answer to the ammeter question resulted from an understanding of science being an on-going evolution of explanations and that these models change over time. For several years, the researcher used an historical model in her teaching that emphasised the developing nature of models and scientific conceptions. Here is a case of a student of about 13 years old being able to enunciate the non-didactic nature of science. It appears that the use of analogies allowed student 1, a highly intelligent student, to conceptualise this framework as well as move his understanding of electrical circuits to the scientifically accepted one.

One student, student 10, developed his own analogy to explain his prediction of the ammeter readings. He stated that it is "like dump trucks taking rubbish to the tip and then going and getting more rubbish etc." (010/0040). Wong (1993) describes how when developing analogies in a classroom the analog and the target are generally defined or implicitly suggested by the researcher or teacher; in this project, the researcher developed the analog in conjunction with the students. Student 10 developed his own analogy to explain the reading on the ammeters and in doing so has exhibiting a trait which Wong links to an independent learner (Wong, 1993). Many high ability students are able to generate their own analogies as seen in the Year 9 geology assignment described in Chapter 4.

Student 26 was able to predict the readings on the two ammeters correctly in Year 7 and Year 8 but used an alternative conception to support his problem solving in Year 8. His answer in the Year 7 examination carefully explained the paper role-play in class. His explanation, however, showed several inconsistencies, which indicated that he had not fully conceptualised the separation of electrons and energy. In his answer in the Year 8 retest, he explained his answer as an analogy:

> Bits of paper are like electrons flowing in a wire. The first ammeter counts how many bits of paper goes to the light bulb and the light bulb is like a resistor which allows less paper to flow through. The second ammeter counts how much paper returns to the battery. (026/0103)

Student 26 was able to derive the correct answer for the reading on the ammeters, and his thinking on the reasons appears to have developed from a description of a class activity using an analogy. Unless he reconceptualises, student 26's incorrect mapping is likely to create problems when he comes to harder problems.

SUMMARY OF YEAR 8 RETEST INFORMATION

The percentage of students predicting the readings on the two ammeters in a simple circuit in Year 8 was very similar to the results in Year 7, that is 74% have the scientists' conception, and 26% hold an alternative conception. About 20% of students have altered their conception since the Year 7 examination, most from an alternative framework to the scientists' framework. This result indicates that for many students their conceptual framework is fluid, taking several months of cognition before they move to the scientist's framework. One student still appeared to be in the transition phase and one student only appears to have reverted to a previous, alternative framework after holding the scientists' conceptual framework for the period between the unit and the yearly examination. This student, due to family problems, would have had no time after the unit to revise or reflect on the work done in class. This result is unexpected. Stocklmayer and Treagust (1993) state that in educating students about electrical concepts, changing student's ideas has proved to be very difficult. Results from this small sample show that high ability students are more able to restructure concepts to fit with the scientific view than other students.

YEAR 9 INTERVIEWS ABOUT THE ELECTRICITY UNIT IN YEAR 7

Follow-up Interviews

In November 1999, six students from Year 7, 1997, were interviewed to assist in answering Research Question 2b: How long do analogies created in the classroom remain with high ability students? and Research Question 3: How do analogies help students in concept development? Approval to conduct these interviews was obtained from the Principal who also approved the content of the information letter given to students at these interviews.

The interviews were undertaken individually in the office of the Head Teacher, Administration, while she was absent. The only persons present were the researcher and the respective interviewee. The interviews, each lasting about 30 minutes, were audio-taped and the researcher took no additional notes. Overall the interviews went smoothly and a good rapport existed between the researcher and the students. The researcher had prepared a list of questions and the interview was structured around these. The interviews were transcribed and coded using the same code used for the Year 7 Yearly examination. The transcribed interviews are presented in Appendix D7.

Prediction of Ammeter Reading

After explaining the reason for the interviews and that the students were not compelled to participate, reviewing the letter to take home to their parents, and asking for permission to audio-tape the session, the researcher presented each student with the diagram of the simple circuit used in the Year 7 yearly examination and the Year 8 retest. The students were asked to predict the reading of the two ammeters and the six students' responses are tabulated in Table 21.

Table 21: Year 9 students' predictions of the reading on two ammeters in a simple circuit

Student number	Reading on ammeter
001	Same
007	Same
013	Same
014	Same
015	Same
018	Different

From these interviews, it appeared that, for most of these students, the move to the scientists' conception of electrical current was stable, though student 18 was still in transition; for instance, when asked to compare the readings on the two ammeters he stated, "I think they are the same" (018/0005). When asked to explain his reasoning he first asked, "Do ammeters measure voltage?" (018/0008). On being told that ammeters measure current, he then asked which way the electricity was flowing? The researcher indicated the direction of the current and student 18 then stated, "Okay ammeter 1 has more current than ammeter 2" (018/0012). The researcher continued by asking student 18 how he derived that answer and he replied with an answer that indicated that he held the alternative concept in which electricity is used up in the light globe.

Student 18's answer in the Year 8 quiz indicated that although he stated that the ammeter readings would be the same he was using an alternative conception in which electricity is used up in the light. On reviewing his explanation from the Year 8 quiz student 18 stated that the "electrons pass through the ammeter and the resistor and the second ammeter. There is no light bulb to take up the electrons" (018/0125,

Appendix D6). He appeared to have changed from the scientists' view, which he expressed in the Year 7 examination, to an alternative conception in Year 8 which remained into Year 9.

When asked to predict the readings on the two ammeters, student 1, with a little wait time, replied confidently that they would be the same. On being asked to explain his answer student 1 stated, "Because ammeters measure current and its the energy that the current is carrying which is being used in the light bulb, not the current itself, and I can't remember most of this stuff" (001/0011). Student 1 answered this question in the Year 7 examination by using the analogy of coal trucks moving back and forward between the battery and bulb. He did not use this explanation in the Year 8 retest, but referred to the model developed in class. In the Year 8 retest he wrote that "The scientific model that was developed where the electrons move through the circuit and the energy gets used in the light then the electrons move back to the battery" (001/0013, Appendix D6). Here student 1's explanation was supported by the introduction of an analogy in Year 7. The analogy and hands-on experiences would appear to have allowed student 1 to engage mentally with the material and bridge his conceptual redevelopment. The reference to models in Year 8 indicated that he was using these to structure his conceptual redevelopment to enable him to problem solve in Year 8. In Year 9, this student made no mention of either analogy or model to explain his answer. He appeared to have bridged the conceptual gap; the movement of electricity in a simple circuit was now part of his conceptual framework and he had no further need of supporting structures to assist in his problem solving.

When asked later in the interview about the coal train analogy, student 1 had no memory of it, yet was able to explain clearly, as were all the students interviewed, the role play conducted with pieces of paper in the classroom. For example student 1 stated "…the people were the electrons dropping off their energy at the light bulb, or whatever it was and they kept on moving" (001/0026). Student 13 was equally clear in his explanation "…everyone was walking around the classroom and there were two people and they were the light globe and they were taking in the paper…" (013/0021).

LEARNING INVOLVES EFFORT

Learning about electricity in Year 7 was not easy and students 14 and 15 mentioned how difficult they found the work on electricity. Student 14 stated that "it was pretty hard to understand electricity at that stage". Although student 14 appeared clear on the separation of energy and current, he initially voiced some confusion, "I don't know if the pieces of paper really go back to the battery"(014/0025). On being questioned further by the researcher as to what returned to the battery, student 14 stated "the people like they're simulating the current" (014/0033). His answers after this point were very clear, stating that "it's not the actual current that gives the light" (014/0041), and "it's just the pieces of paper, they're the only thing that changes" (014/0052). The interview allowed student 14 to talk on a one-to-one basis and clarify one point of confusion that he found with the analogies in Year 7; he appeared to have moved wholly to the scientists' conception at this point although his explanation mixed aspects of the analog with the target.

The perception of difficulty voiced by student 14 can better be understood if it is viewed from the perspective of educational philosophy. Students entering North Sydney Boys High School have been outstanding scholars in primary school, either attending Opportunity Classes in Years 5 and 6 or being the top student in their respective primary school. They have succeeded in a historically behaviourist education system where attention has focused on performance rather than the reasoning that prompts students to respond in a particular way. This system has resulted in an assessment system that focuses primarily on memorisation and rote learning (von Glasersfeld, 1995). Student 15 is a typical product of this sort of background. He is a very earnest, motivated student, and also appears to be in a period of transition in his understanding of the flow of electricity in a simple circuit. In the interview, he initially stated that the readings on the two ammeters would be the same but when asked to explain his answer said:

> … OK this is what I remember, we were trying to figure out, it can't be the same actually, because how does the battery lose electricity, so actually, maybe it's a bit less on this one each time. It reduces the reading. That is all I can say. (015/0019)

On further questioning, student 15 remembered that the role-play involved people acting as electrons and stated:

> basically we were showing that they are they are already, they are all there, and so we don't make electrons we are just simulating them, so they are all already there and electricity just passes through them". (015/0036)

He was aware that the role-play in Year 7 separated the concept of electrons and energy but he was not fully conversant with the new conception and asked about the use of the role-play in Year 7. This student remembered being concerned about a perceived waste of time because he saw science as a series of facts to be learnt and liked to be told what he had to learn. The researcher remembers him as being concerned if he was not in the top quartile of the class. He found the time involved in working through the exercises frustrating, as can be seen by his following comments:

> Well, I mean it wasted time getting people into line, I mean it is a bit distracting. I remember it wasn't all that clear at the time. You have to think about it as well. It doesn't just happen when you get into line, you don't understand it straight away, but I mean it helps. I think it helps in different ways because then you realise what exactly is meant when you move. (015/0050)

It is clear from student 15's comments that changing conceptual frameworks involved effort and also created some anxiety for him. This anxiety could be in part due to the fact that for a part of the course knowledge cannot be transferred from teacher to student, it has to be reconstructed by the student and this takes time because the knowledge cannot be pre-digested. In this case, the learning involved the introduction of an analogy, reflection time, as well as class discussion. From student 15's answers during the interview, it was apparent that changing a student's conceptual framework can take several years and students can remain in a transition situation for a long period, until the concept is addressed again.

High Ability Students' Views of Learning

Students in selective high schools are all high ability students with a range of ability and learning often much greater than that of students in a comprehensive high school classroom. The last part of the interview with these students asked about their learning. The model of learning identified amongst the Year 11 students, described in Chapter 4, appears to be repeated amongst the Year 9 students. The students interviewed were all very efficient learners. Student 1 said that he usually picked things up as material was presented, but explained how he remembered large amounts of information when required, or when he found a topic interesting. He gave an example of learning about fossils in Year 8 when he decided to learn the table of geological time. Student 1 also described where he developed his own chemical model. When asked how he tested this model, he explained that he used it to answer questions in the unit test and that it had stood up, so continued to use it.

The ability to learn material, which was interesting, and retain it for a long period of time was a pattern repeated across all students interviewed. Students were able to clearly describe lessons from Years 7 and 8 that stood out to them. Student 13 described a Year 7 lesson where "… we made oxygen and carbon dioxide" (013/0110), a lesson that occurred two years previously. This group of students also mentioned the importance of visualisation. Student 14 remembered a geology lesson where he understood about the effect of erosion on igneous intrusions, "It had a big diagram and I could see it changing. He'd [the teacher] rub it out and then draw the next stage and so on. You could just see the process and steps and how it happened" (014/0096). When pressed for further explanation, student 7 said that he found introductory lessons interesting as they described the basic structure of the unit. He stated that if he could determine a pattern then he found learning easy, "It is easier to see in the mind if there is a pattern" (007/099). This is the reason that the researcher believes that analogies fit well in the learning of high ability students. The analogy is a way to visualise and to create interest in the concept under discussion by increasing the chance that the student will engage with the material, and remember it. In turn, this allows the student to reflect. When questioned about learning for tests, student 13 also described getting out his book and reading over the notes and perhaps making some notes.

CONCLUSIONS

The data analysed in this chapter have shown that the majority of the Year 7 students in this sample had retained the scientific view of electric current developed in class though some students were unable to correctly predict the readings of the two ammeters in the circuit. However, by Year 8, a similar number of students had retained the scientific conception of electric current though several students had changed their predictions since the Electricity examination in Year 7. Comments in interviews with six students in Year 9 illustrated that analogies in class are retained for later use and that the analogies helped students in their concept development. How specifically these data are used to answer the research questions are described in Chapter 6.

In the next chapter, the conclusions and recommendations, which arise from this thesis, are summarised. The conclusions are presented in the light of the research questions put forward in Chapter 1. Further possibilities for research are examined including the development of diaries and their role in monitoring conceptual change.

CHAPTER 6

RESEARCH OVERVIEW, IMPLICATIONS, RECOMMENDATIONS AND CONCLUSIONS

We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time

From Little Gidding (Eliot, 1941, p. 59)

As the researcher reviews the journey undertaken in the writing of this thesis and the analysis of the assignments, tests and interviews, she feels the truth of T. S. Eliot's verse from Little Gidding that the end is just the beginning. The search for understanding of the teaching process, which has driven this work, questioning existing structure, which confine the daily milieu, and trying not to be trapped in busy work, does allow the researcher to reflect and "know the place for the first time".

OVERVIEW

This chapter draws together the findings of the case studies with the Year 9 and Year 7 groups as well as the Year 8 review and interviews in a research overview where the research questions proposed are answered with reference to these studies. The development of a model of learning for high ability students is presented and the implications of these proposals for teaching practice in science are discussed, as are implications for the teaching and learning of high ability students in all subjects.

INTRODUCTION

This thesis described a series of case studies relating to the researcher's teaching in Year 7 and Year 9 classrooms in a selective boys high school in Sydney, New South Wales. The studies were undertaken using a naturalistic research framework where findings from one case study informed later ones in terms of the case studies conducted and their nature. Data were analysed using a phenomenographic approach and were interpreted within a constructivist framework.

The research problem addressed in this thesis was grouped around three main research questions:

1. Can high ability students create their own analogies? Within this question are the sub-set of questions:
   - 1a What type of analogy do students create?
   - 1b Can students deconstruct their own analogies?

2. What role do analogies play in learning? Within this question are the sub-set of questions:
   - 2a What type of analogies are the most effective for supporting conceptual change in students?
   - 2b How long do analogies created in the classroom remain with high ability students?
   - 2c If students revert to alternative analogies what happens to the original classroom developed analogy?

3. How do analogies help students in concept development?

These research questions were based on several premises presented in Chapter 2 including the understanding that learning is an active process; students are not intuitively aware of the structured nature of the language of science where analogies are an integral part; and when made aware of the constructed nature of the language of science students are able to identify analogies in scientific text.

During the internalisation of concepts, analogies allow students to function and solve problems in new situations (Wong, 1993). The initial case study set the scene for this thesis by focusing on the inability of several students to relate classroom information to their life out of school and the compartmentalisation of information by students. Subsequently, the research focused on analogies as a tool to link unfamiliar science concepts to concepts and objects familiar to the student.

The group of case studies, which occurred over three successive years, reported the results of an analogies assignment completed by 9S1. This assignment required students to identify analogies from the geology unit The Active Earth. As well, students were required to develop their own analogies and then deconstruct them using the FAR approach (Treagust et al., 1998). The researcher found that as well as including information about analogies in the introduction to the assignment, high ability students needed to be formally introduced to analogies because many students were unaware of them from science or other learning. When introduced to analogies, high ability students were able to identify analogies from a range of material including text, audiovisual, classroom models, practical work, demonstrations and discussion.

RESPONSES TO THE RESEARCH QUESTIONS

Research Question 1: Can high ability students create their own analogies?

In this study, students were able to create their own analogies. From the student discussions and interviews it appeared that many high ability students develop their creative thinking through the four stages preparation, incubation, illumination and verification ascribed to Wallas (cited in Dreistadt, 1969). The classroom became the preparation phase and the incubation phase is where the students reviewed the assignment and thought about what target and analog could be used. The illumination phase was almost like a Eureka stage as the students recognised an analogous situation and then started mapping to see whether it stood up to examination. Students completing this assignment of creating their own analogies seemed to require a period of time to consider the requirements and many students referred to the need to discuss their ideas with other students to confirm and develop their thinking.

Research Question 1a: What type of analogy do students create?

The types of analogy that students developed seemed to be associated with periods of time where little overt thinking occurred such as brushing teeth or sanding wood in technology lessons, supporting the idea that these analogies were developed during a period of contemplative activity. A second group of analogs were associated with body parts indicating that these analogs emerged as students were sitting and not really thinking about anything in particular, just looking at their hands or in the mirror.

Research Question 1b: Can students deconstruct their own analogies?

When asked to analyse analogies found in the literature, in classroom teaching or those that the students themselves developed, these high ability students had difficulty mapping the similarities and differences between the analog and the target. Student 98 is similar to most students in this regard in choosing the analogy of a hen's egg being similar to the Earth. He described how the analogy showed the thinness of the crust of the Earth but was unable to list any characteristics which were similar; the only dissimilarity he described was that the egg was not Earth-shaped. This is an area where further research is needed to confirm the extent to which students are able to map analogies or whether this result was due to insufficient time being given to students to practice this skill with teacher support before attempting the assignment on their own.

Research Question 2: What role do analogies play in learning?

This research question was answered from several of the case studies. With the Year 9 case studies, students were able to construct their own analogies and in this process were able to tap deep learning processes, as reported by students in later interviews. This part of the assignment caused anxiety but the analogies developed by most students allowed them to reflect on the concepts being developed and provided a link to everyday experiences. Some students used humour in the construction of their own analogies, an indication of their cognitive interaction with the concept. The use of analogies allowed students to create links to the target and were a powerful interactive learning strategy in the classroom. Analogies allowed students to link everyday situations and objects to scientific concepts and as such they are assisted in helping students bridge to higher learning, across Vygotsky's zone of proximal development.

The case studies located in the Year 7 classroom were also designed to answer Research Question 2. The analogy developed in the classroom assisted all students to move from an alternative conception of electricity flow in a simple circuit to the scientists' conception over the course of the unit by separation of the two components to electrical flow – a carrier and something that is carried, which the students called energy and modelled as pieces of paper. The creation of the analogy provided students with a framework within which they could reason. Six weeks after the teaching of this unit, several students reverted to an alternative conception of electricity while still using an analogy to support their reasoning. One of these students used an incorrect interpretation of the analogy created in class by including a comment made by the researcher while a role-play of the analogy was being undertaken. This situation highlights the care that needs to be taken in formally mapping the target and analog when such an important analogy is being developed. Again the role of the analogy assisted those students using visual, aural and written styles of learning as well as enabling bridges between the students' world and the world of science.

In the case study in Year 8, several students moved from their alternative conceptual framework to the scientists' framework or from the scientists' framework to an alternative framework. The students had no formal instruction in electricity over this time. For those who moved to a scientists' conception, analogies allowed them to move their conception and indicated that changing a conceptual framework can occur long after the formal instruction has been completed. Teaching with analogies provided students with a framework to attach the new concepts. Several students who had used analogies to support their answers in the Year 7 examination used sophisticated scientific explanations in Year 8. It appeared these students had moved through the transition phase and no longer required an intermediate position to support their thinking.

Research Question 2a: What type of analogies are the most effective for supporting conceptual change in students?

Duit (1990) supports the idea that one of the main strengths of analogies is their ability to provide a visual link between the known and the unknown. This view is supported by this thesis and the analysis of the Year 9 case studies which indicated that analogies that provided a visual link to the target were more often developed by students. In the Year 9 assignments, students spoke of the effectiveness of a visual link that analogies provide, for example, in describing analogies of the Earth's structure, student 93 stated "An onion is something very easy to visualize…it is shaped like the Earth" (Appendix D2 093/0018).

In the Year 7 Electricity unit, the use of an analogy based on an activity carried out in the classroom, with visual and kinesthetic inputs, supported the change in conceptual understanding of the whole class by the end of the teaching sequence. This again supports the thesis that analogies are very powerful, allowing learners to develop known visual links which are easily able to be recalled, to support a new conceptual framework. For example, when questioned in the yearly examination, in a Year 8 retest and in interviews two years later, the analogy and the activities which were used to develop it were still able to be recalled; student 001 stated: "…the people were the electrons dropping off their energy at the light bulb, or whatever it was, and they kept on moving" (Appendix D7 001/027).

Research Question 2b: How long do analogies created in the classroom remain with high ability students?

This research question is answered by the case studies with Year 7 and the Year 9 and Year 11 interviews. For some students the analogy remains for several months providing a scaffold for the student to problem solve while their concepts are in a state of transition. For example, in the Year 8 retest several students still used analogies to support their answer to the readings on the two ammeters such as student 2 who described how "Everyone in the class walked around the room with a piece of paper" (Appendix D6 002/0184). For others who have made the conceptual change, the analogy is forgotten. One such student in this thesis is student 1 who appeared to use the analogy in Year 7 as a transitional support but by Year 8 had moved totally to a scientists' conceptual understanding of electric current in a simple circuit. When asked the reason for his answer that two ammeters in a simple circuit would have the same reading, he described the coal truck analogy in the Year 7 examination, but made no reference to this analogy in his Year 8 answer, and instead stated that "... the electrons move through the circuit and the energy gets used in the light while the electrons move back to the battery" (Appendix D6 001/013). When interviewed in Year 9 student 1 replied to the same question, "… because ammeters measure current and it's the energy that the current is carrying which is being used in the light bulb not the current itself" (Appendix D7 001/011).

It is possible through the use of the longevity of analogies and by asking students to explain their reasons for a particular question to determine the conception with which a student is working. This was seen with student 18, who although he stated correctly that the readings on the two ammeters would be the same in Year 7 and Year 8, in Year 8 stated in his explanation that there is "… no light bulb to take up the electrons" (Appendix D6 018/0127).

Research Question 2c: If students revert to alternative analogies, what happens to the original classroom developed analogy?

Duit (1991) describes several disadvantages of using analogies to engender learning including the problem of misconceptions transferring into the target domain. Several students in the Year 7 examination, Year 8 review and Year 9 interview case studies reverted from the scientists' understanding of electric current in a simple circuit to an alternative conception. Some of these students modified the analogy developed in Year 7 to fit their existing conceptual framework such as student 3 who, in referring to model C where the readings on the ammeters differ, stated that this is "because if the ammeters were the same then the battery would not run out, whereas if the model I think is the correct one the battery will eventually run out"(Appendix D5 003/00049). Student 24, describing the clashing current model of electrical flow, stated "in class we developed a model that electricity flows to the battery through both leads at the same amount of amps. This explains why the battery runs out and it was proved possible with an ammeter" (Appendix D5 024/0437).

Students can mislearn information which can result in modification of the analogy to match their incorrect understanding. One such student, student 11, who stated in his explanation that "ammeters measure amps which is the amount of energy in an electron" (Appendix D5 011/0206). Student 11 was able to separate energy and electrons but had incorrect information to the explanation that "energy has been used up in the bulb and the first ammeter still has amps in the circuit but the second one didn't" (Appendix D5 011/0209).

Research Question 3: How do analogies help students in concept development?

Two years after the completion of their analogies assignment, another case study was undertaken to answer this research question. After interviewing several students, it became clear that analogies enabled students to link their thinking with a concrete activity that occurred previously. Students had clear recollections of what they were doing, thinking and feeling at the time of writing the analogies assignment in Year 9. When asked at interview in Year 11 for example, student 93 described sanding a piece of wood and "the particles of wood came off slowly as sawdust and I sanded down until … and I changed the shape altogether which was similar to the pattern of erosion caused by wind or water" (Appendix D4 093/032). Analogies also provide a tool for students to use as they interact with scientific concepts and permit discussion and so allow students to test ideas. A theme which recurred throughout the research was that of students interacting with others to clarify their thinking. Comments such as "I discussed it with someone else and what they were doing" (Appendix D4 040/074), and "I was talking to student 100 at the time about it " (Appendix D4 093/025), indicate that having to create an analogy allows students to test their ideas amongst each other. Analogies provide a means to allow word meanings to develop within a social context.

IMPLICATIONS OF THE RESEARCH

There are implications of the case studies undertaken as part of this thesis that warrant discussion.

1. The use of analogies as tools for both research and teaching depends on students recognising their existence and so involves structuring the process through which analogies are introduced into teaching.

2. Development of material is needed to assist teachers to introduce analogies more effectively into their teaching and to encourage overt mapping between target and analog using the FAR model as a scaffold for this process.

3. Assessment tools need to be developed which incorporate sections where students have to present their reasons for a particular response.
4. The provision of inservice training is required to assist teachers about the learning of high ability students.

Each of these topics will now be discussed more fully.

Structuring the process through which analogies are introduced into the classroom

From analysing the responses of students about their awareness of analogies, it is apparent that many students are unaware of the existence of analogies in science and other subject areas at school. This is probably due to a lack of critical awareness amongst students of the material presented and an unawareness of the constructed nature of science so that information is accepted at face value. For effective use of analogies, students need to understand that the reality of science is data and that the body of knowledge learnt is a series of models and analogies to explain the data (Stocklmayer & Treagust, 1996). If viewed from this framework, then science as public knowledge is not so much about discovery as about a carefully checked construction of the world itself. Students need to be aware that the world they learn to know is a construct of theoretical entities, organised by ideas such as evolution. If students are to be able to contribute to the ongoing construction they need to be aware of it and able to use it themselves. This process should commence when students enter high school. As the experience from the Year 7 electricity unit indicated students are able to construct and use analogies to support their conceptual development. Assignments and classroom activities that allow the constructed nature of science to become overt should be included in a sequential literacy program in the junior science program.

Developing information to assist teachers to introduce analogies more effectively into their teaching

To introduce analogies effectively, in-service programmes need to be implemented to inform teachers in selective high schools as well as comprehensive high schools of the importance of analogies in their teaching and their ability to engender high level thinking in gifted students. Many teachers in the area of gifted education probably assume high ability students know this information intuitively.

Analogies are a powerful tool in the development of concepts in science. The use of analogies becomes more effective if students are able to map the analogy for similarities and dissimilarities using the FAR procedure (Treagust et al., 1998) as a scaffold. The process of mapping needs to become overt and exercises developed to introduce analogies and to allow teachers and students to model the process if the problem of misleading learning to be avoided (Duit, 1990). Many high ability students were unable to map analogies effectively by themselves after a small amount of introductory work. Research by Thiele (1995) showed that students who performed better at chemistry were able to map analogies more fully and more accurately than their lower performing peers. From this research, it appears that students in a transitional conceptual framework retain the analogy for a long period of time. If the analogy is not mapped fully students can alter the analogy to fit an alternative framework or can develop an alternative conceptual framework in the first place.

Analogies can engender high level thinking in gifted students and is one of the strategies identified by the Williams Model of Affective Interaction (Williams, 1986). However, the research reported in this thesis found that many high ability students in Year 9 were unaware of the existence of analogies in science, let alone as part of general language, until the analogies were made overt as seen in the introduction to the Year 9 assignment. One of the functions of developing literacy across science as well as the whole secondary school would be to inform students of analogies and allow students to develop their own in whatever topic is being presented at that time. The process of having students develop their own analogies allows them to interact with both the science concept, or other concepts being introduced at that time, and the students' own reality can engender the deep cognition required to support conceptual change. The results of this thesis have affected the way that the researcher's own teaching has developed as she is far more aware of the importance of the structure of language as a tool for evaluating student understanding. Student writing has become a tool both for the student and teacher to evaluate understanding and the developing nature of science has become a constant theme. This has occurred through the use of oral exercises incorporating analogies and in requiring written and oral explanations. Clarification of ideas has developed through the use of short written exercises; as well as the use of two part questions, one part a straight answer and the second an explanation of that answer. These activities have sharpened the researcher's focus in the classroom and this may assist other teachers similarly.

Develop assessment tools which incorporate sections where students have to present their reasons for a particular response

The incorporation of a section in the Year 7 electricity examination where students were required to firstly give a response to a problem and secondly give their reasons for that response alerted the researcher to conceptual frameworks operating in the classroom. This understanding was responsible for the inclusion of several case studies in this thesis. The effectiveness of teaching is increased if one knows the framework students are using. The use of outcomes-based teaching and reporting could be enhanced if assessment tools incorporated sections for students to give not only a particular answer to a question, but also extended responses as to why the student gave a particular test response. This type of assessment would be especially helpful in targeting classroom teaching more effectively.

Presentation of information about the learning of high ability students and its implication for teaching in selective high schools

Teachers allocated to teach in selective high schools often have no pre-service training about the learning requirements of high ability students. Rather they bring with them experiences from teaching in comprehensive classrooms. High ability students are mostly high ability readers and are able to read for meaning very efficiently. Their ability to take in information from textbooks and check this by reading and internally reviewing end of unit questions is, for them, an efficient learning process for factual material. If interested and motivated, they are able to commit large amounts of information to memory; for example one student learned the geological time scale, and other students discussed preparing for unit tests by memorising. High level learning was seen to be supported through discussion with peers and other significant adults, such as parents, as illustrated in the students' reflections about the analogies assignment in Year 9. High level learning was also supported by allowing time for reflection.

LIMITATIONS OF THIS STUDY

A weakness of this research project was that data collection, though expected to continue to saturation within the framework laid down for its effective use, was limited by the school year. In this particular project, data collection ceased at the conclusion of each school year rather than at saturation.

The location of the research in a busy high school classroom created constraints on the development of material. Each unit of work was completed within a five or six-week block and lessons were continually lost due to camps, excursions, assemblies, musicals, and sporting events. Added pressure came from the policy of across-class testing where all classes in each year undertake the same end of unit test and a very competitive group of students who preface each piece of work with the question "Will this be in the test"? To reduce this constant pressure, the research materials developed for the Year 9 class were included as part of the normal assessment procedures where alternative class assessment strategies were highlighted as part of the specifications for students entering the class. Assessment procedures varied from other classes, gave insight into the learning of high ability students and supported the role of teacher-as-researcher using student writing as data (Beasley & Riordan, 1981).

METHODOLOGICAL SIGNIFICANCE OF THIS STUDY

The problems confronted as the researcher took on the role of teacher-as-researcher for the purposes of this thesis were many and included the necessity to deal with the immediate issues of the classroom, faculty and school and so push the less obvious needs of the research to one side, a problem identified by Wong (1995) where he described his optional role as researcher in the classroom as opposed to his role as a teacher. In retrospect, Wong (1995) was correct when he identified that the conflict of the teacher-as-researcher was that at all times the quality of teaching had to take priority over the quality of research. The use of a naturalistic approach, however, allowed the research to be embedded within her own classes and gave this thesis its strength. This type of research allowed the researcher the flexibility to follow areas of interest as they appeared during the life of the project, to create assessment tools which met both the needs of the research and the faculty, and allowed the researcher to monitor her own educational practice and develop more effective teaching procedures.

FINAL COMMENTS

As the researcher comes to the end of this study, it really does feel as though it is the end of a long journey. The choice to move into the classroom as both teacher and researcher was challenging and forced the researcher to review both practice and learning in science education. The effort required to sit and code data and search for meaning and to place this research within a theoretical framework has introduced research and ideas which contributed to the teacher's conceptual reassessment and has changed her view of students and learning. This journey has forced the allocation of time to reflect on practice and the learning occurring in the classroom, for which she is grateful. The students taught after this point will not be aware of changes but the researcher is more confident in guiding staff and students in the development of students' conceptual frameworks within the school setting.

Added benefits gained from this research include an appreciation of the importance of teacher-training for teachers involved with high ability students, the promotion of classes along the lines of 9S1, and the need to provide reflection time at crucial phases in the learning process.

The essential conclusion of this study is that high ability students do not see analogies in the science literature unless they are made overt and so do not see the constructed nature of science. However, once seen and understood, student-developed analogies can be a significant tool in supporting high level learning in gifted students as long as time is given to allow the development of the skills to fully map the analogy and the target concept.

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APPENDICES

Appendix A:

A copy of the request presented to the Principal, North Sydney Boys High School for permission to conduct research in the author's classroom.

Appendix A: A copy of the request presented to the Principal, North Sydney Boys High School for permission to conduct research in the author's classroom.

To: Principal, North Sydney Boys' High School

Topic: Proposal to conduct research in science classes at North Sydney Boys High School

As part of my studies at Curtin University of Technology, Perth I have developed the following research proposal which has been approved by the University and now request approval to conduct the research set out below in my classes at NSBHS. All students' approval will be obtained prior to using any of their work and names will be suppressed in any publication of this work.

Research topic: An Analysis of Analogies Constructed by Students in a Selective High School

Abstract

Research in science education over the past twenty years has emphasised the importance that active cognition plays in conceptual understanding. Students in schools formulate knowledge and relate it to their own purposes using speech and writing. The use of analogy in the development of science theory and concepts is not recognised by many students in high school. By focusing on the constructed nature of science and analogy, the student is able to engage their own thinking through introspection and revision. Students then have a powerful structure with which to deconstruct and reconstruct their scientific understandings.

This research aims to highlight the use of analogy in two junior high school classes to determine whether students recognise analogy in science text, and, the level of analogy use that high ability student students recognise. The study also aims to explore the ability of high ability students to create and analyse their own analogies and the long-term viability of these analogies.

Background

Theoretical framework

Constructivism is a theory about knowing (von Glasersfeld, 1989). It describes the way people develop their ideas, or schemes of the world around them. Within this philosophy of knowing the development of ideas and concepts is seen as an ongoing process throughout life.

Constructivism is not a new theory but the refinement of a series of beliefs that have been around since at least the eighteenth century (von Glasersfeld, 1989). Piaget with his stages of intellectual growth of children has been rediscovered as a constructivist. Piaget was concerned with the way children construct knowledge and he recognised the "self regulation" process in individual learning.

Constructivism is an active process involving mental processes, experiences with the environment and social interactions. Learners, in order to construct their view of the world, need not just experiences but also the models and concepts of conventional science. The challenge, according to (Driver, 1989), is for the science educator to assist learners to construct these models for themselves. Learners then appreciate the domains of applicability of the concepts and within such domains are able to use them.

Children actively search for regularities and meanings in situations. They come to the classroom with developed ideas or schemes about the natural world around them (Bauersfeld, 1988). They have had for example, experiences about what happened when they push, pull, drop, or kick an object and have used these experiences to develop concepts about how things feel and move.

Learning: Culture and language

Learning about the world does not take place in a social vacuum but is shaped by the medium used for its exploration, language. Children use language and culture to help them imagine and think. Phrases such as "shut the door and keep the cold out", and " feed the plants", provide through culturally accepted metaphor, ways of representing the world. Language, whether spoken, internal or written is culturally embedded. Language is also the medium through which we interpret and communicate our experiences of reality. This relationship between student's schemes of understanding and schemes available through culture and language has been explored by (Solomon, 1992) and it appears that reality is a function of an individual students ability to describe it and can only exist through the social construct of language.

Science constructs

A logical consequence of the link between reality and language is the rejection of an 'objective base' of observations against which theories about the world can be checked. Although we may assume the existence of an external world we do not have access to it. (Tobin, 1991) believes that as our senses are subjected to a translatory process in our cortex they will inevitably be affected by a person's individual chemistry, previous experiences and reactions to them. All experiences are therefore subjective. Knowledge is seen as a construction of reality through language and adapted as a result of experiences and reflections.

Science as public knowledge is not so much about discovery as about a carefully checked construction. It is the task of science to invent and develop theories that aim to represent the world. Scientific ideas do not result from direct interactions with phenomenon. These theories pass through a complex process involving communications and checking through major social institutions of science before being validated by the scientific community. Our theories are constructs of the known world, but not of the world itself, and we may always be wrong. We live in a construct of such theoretical entities as atoms, ions, fields and fluxes, genes and chromosomes, and organised by theories such as evolution. These take on a "reality" separate from truth, which constructivists assume will be forever elusive (Driver & Oldham, 1986). The social construction of science means that an individual cannot discover the ideas about science; learning science means being initiated into the culture of science.

Relating language to analogy

The terms analogy and metaphor are often used interchangeably. For the purposes of this research the term metaphor will be confined to a literary context and the term analogy to a scientific context. This refinement is used by (Glynn, 1991b).

The Macquarie Dictionary (Delbridge et al., 1991) defines analogy as "an agreement, likeness, or correspondence between the relations of things to one another; a partial similarity in particular circumstance on which comparison may be based".. Analogies are ways of determining similarities between different ideas, objects and/ or concepts.

Why is analogy important in science education?

The importance of analogy to the understanding of science theory and concepts dates back many years. N.R. Campbell (Campbell, 1957) said in 1920 that ..."Analogies are not "aids" to the establishment of theories: they are an utterly essential part of the theories". Glynn (1991a) quotes Oppenheimer in 1955 as saying that ..." Analogy is an indispensable and inevitable tool for scientific progress" (p. 220).

Goswami (1992) in her review of analogical reasoning in children also believes that analogy is at the core of relational reasoning and describes analogy as appearing to be a fundamental component of intelligence.

More recently Lawson (1993) specifically linked the role of language to concept acquisition and development. He sees analogies as being a specific language tool by which scientific concepts can be acquired and the means by which scientific reasoning skills can be developed. Analogies are believed to help students integrate new material into their existing experiences. This is especially true where students, as in science rely on textual material to learn science. Analogies can, if the analogy is relevant to the reader, allow students to integrate the new understandings with their pre existing knowledge.

Types of analogies

Analogies are constructed by relating an unfamiliar concept with a target concept. This is more easily done if the new concept is embedded within an overall or superordinate concept. Glynn (1991a)outlines this with the following example.

Superordinate concept, principle or formula

Analog ....compared with........................ Target. This results in the following construction:

Feature .... compared with........................ Feature

The development of analogs is to a large part determined by the superordinate concept. The visibility of a superordinate concept allowing for the development of other analogs in other contexts (Glynn, 1991). This can be seen in the following example.

Circuit (Superordinate concept)

Water circuit...Electric circuit
Water...Electricity
Flowing water..Electric current
Pipes...Wires
Pump.. Battery
Pressure..Voltage
Filter... Poor conduction
Reduced flow.. Resistance

The construction of good analogies is an art rather than science according to Glynn (1991), with good analogies comparing a number of similar, conceptually significant features. Poor analogies can be due to the features of the analog being unfamiliar to the audience. For example few students in Chemistry classes are familiar with plum puddings as an analogy for an atom.

If the compared features are unfamiliar to the audience then analogies can diminish understanding and lead to misunderstandings. Misunderstandings can also result from the use of vocabulary outside the students' range of the use of different discourse rules, for example where the analogy uses a negative question and the student interprets this as fact.

Duit (1991)warns the student to use analogies carefully because at some point every analogy will eventually break down.

Collins and Burnstein (1989) have identified three different analogy types that are dependant on the relationships that analogies compare. These are

- ***systems analogies***
- ***concepts analogies, and***
- ***property analogies.***

Systems analogies refer to relationships such as that between the solar system and an atom, while concept correspondence analogies relate to decisions about the properties of the two concepts, for example whether an x is a y. Property correspondence analogies compare a particular property of two concepts, such as whether a three-inch disc is more like a dollar coin or a pizza.

Goswami (1992) believes that children have the ability to reason about relational similarity from an early age, as long as they have knowledge of the relations used in the analogies. She states that any analogical development might consist of a metacognitative understanding of analogy rather than the development of ability to reason about higher- order relations per se.

Use of analogies

While students are aware of and can use analogies from an early age there does appear to be a change in the way students use models as they get older.. (Grosslight, Unger, Jay, & Smith, 1991) identified three general levels of understandings about models. These levels are

***First level understanding*:** At this level students see models as simple copies of reality

Second level understanding: Students at this level of understanding are aware that they can make conscious choices to mediate the way that the model is constructed. While students using models with a second level understanding are aware that the model can change. Students using second level understandings have conceptions of a different spatiotemporal view of the model rather than different theoretical viewpoints. Students using models at this level see models as a means of communication about real world events rather than testing ideas.

Third level understanding: This level of understanding is characterised by three factors,

1. firstly the model is used to test an idea,
2. secondly the person modeling takes an active role in its construction, and,
3. lastly models can be subjected to tests in the service of forming ideas.

In general, students seem to have had little experience with scientific models (Grosslight et al., 1991) and students accept models as they do theories as fact rather than a construct of science. There appears to be a need for the science curriculum to provide more overt experiences of the
Place of models in science. These experiences should include both models developed by others as well as student-developed models. It is only with experiencing the constructed nature of models that students will be able to appreciate the place of language in the construction of science.

In Conclusion

Research in science education over the past twenty years has emphasised the importance that active cognition plays in conceptual understanding. It seems, however, that research on the mediating role of language in the negotiation and construction of meaning has not been emphasised (Wilson & McMeniman, 1992), 1992). Barnes (1986) argues that students in schools formulate knowledge and relate it to their own purposes using speech and writing. These forms allow the student to engage their own thinking through introspection and revision. By focusing on the constructed nature of models and analogy students have a powerful structure with which to deconstruct and reconstruct their scientific understandings.

If students are aware of what they know then they are able to change it (Wilson & McMeniman, 1992).

The purpose of the study

While much has been written of the importance of language and analogy in mediating understanding it is my experience that few if any students are aware of the constructed nature of science and so of analogy in their learning. Students accept the written word as "truth" and scientific theories as reality. (Claxton, 1996) at a recent seminar stated that when information was taught as 'could be' statements rather than 'is' statements students' epistemology shifted radically.

Teaching which makes analogies overt and allows students insights into the theories of science by giving them control over their formation allows for greater student participation in the learning process.

Thiele and Treagust (1991) believe that while there has been an increased interest in the use of analogies to aid student conceptual understanding little has been determined about the learning processes associated with analogy assisted instruction. This they believe is due to the studies only measuring student recall of learned material.

The research seen in the area of analogy has focused on students in a comprehensive school setting. There has been little research carried out on how high ability students interpret and develop analogies. Gabel and Sherwood (1980) go so far as to report that analogy may not be especially useful for more academically capable students. Curtis and Reigeluth (1984) on the other hand believe that analogies initiate important visualisations and therefore more efficient learning. This research is designed to determine how high ability students determine and develop analogies.

The study will investigate the effect of analogies in developing understanding of concepts with a group of high ability students. The study will evaluate student's interpretation of analogies used in text and in the classroom. It will also investigate how high ability students develop their own analogies and the strength of these analogies over time.

The result of this work will give insights into the learning processes of high ability science students. It will also determine the variability in one class of high ability students in science. These insights will enable more effective teaching and resource development both for these students, and, indirectly for all science students.

Research questions

- Do high ability science students recognise the use of analogies in science text.
- Can students develop their own analogies?
- If students do develop their own analogies, how do high ability students develop analogies?
- Which level(s) of understanding do the analogies of a high ability science group of students fit within?
- Do analogies aid in an understanding of concepts in high ability science students.
- What is the long-term viability of student developed analogies?

Research design

The unit of analysis will be the class but I intend to interview individual students in the class to further determine the effect on individuals of the overt presentation on analogies in the teaching.

Data will be collected at three points through the research period. The first was in 1997 (a Year 9 Geology unit), the second and third during 1997 and 1998. This will be during a Year 9 Chemistry unit and during the Geology unit again. The Chemistry unit runs in Semester 1 and the Geology unit in Semester 2.

The data will be a class assignment that will focus on the students' ability to recognize, deconstruct and create analogies.

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Appendix D1:

Transcribed survey completed by Year 9S1 (1997).

9S1 COMPOUNDS DIARIES TRANSCRIBED AND CODED

Note: The student numbering was altered during the writing of the thesis and so the student order is not sequential.

Date: 19 March 1996

STUDENT NUMBER 057

001	*The work in this class is sufficient*	
002	The work is sufficient	
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004	Science is about the same as Year 8	TSAM/57/004
005	*I have/have not learned anything new in this course and I am bored?*	
006	No, it is interesting	TINT/57/006
007	*The subject matter relates to life outside the classroom?*	
008	A bit	RLLI/57/008
009	*This course is different t any other I have done in junior school?*	
010	It is basically year 8 'matter"	TSAM/57/010
011	*Any other comments on the unit Compounds*	
112		

STUDENT NUMBER: 058

001	*The work in this class is too easy/too hard?*	
002	The work is not too easy but is usually understood well	TLJR/58/002
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004	Compared to other subjects I spend a reasonable amount of time probably more than in Year 8	TSSA/58/004
005	*I have/have not learned anything new in this course and I am bored?*	
006	I have learnt a fair bit in this course	LEUN/58/006
007	*The subject matter relates to life outside the classroom?*	
008	A bit but not that much	RLLI/58/008
009	*This course is different t any other I have done in junior school?*	
010	This course is not that different to the one in Year 8	TSAM/58/010
011	*Any other comments on the unit Compounds*	
112		

STUDENT NUMBER: 059

001	*The work in this class is too easy/too hard?*	
002	The workload is very satisfactory. We are doing a lot and learning from it.	LEUN/59/002
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004	In fact I've spent more, because I want to understand what we are doing in class	TSMO/59/004
005	*I have/have not learned anything new in this course and I am bored?*	
006	I have learned anything new in this course and I am not bored. It is very interesting, especially the experimental work, I think I have learnt a lot from It.	TINT/59/006 COMP/59/006
007	*The subject matter relates to life outside the classroom?*	
008	Most of it does fit this description. Only some of the less common compounds have been different to everyday life.	RLST/59/008
009	*This course is different t any other I have done in junior school?*	
010	It is far more challenging and interesting	TINT/59/010 TLCH/59/010
011	*Any other comments on the unit Compounds*	
112	Mrs. Crowley is a terrific teacher, and she has explained all problems in great detail. Even with the recurring questions she has answered the whole question so the whole class has understood. He compounds work was very interesting and I think I learned a lot.	TEEX/59/112 TEQU/59/112

STUDENT NUMBER: 060

001	*The work in this class is too easy/too hard?*	
002	The work is not too hard but not too easy either	TLJR/60/002
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004	I have spent more time this year to keep my standard up throughout the year	TSMO/60/004
005	*I have/have not learned anything new in this course and I am bored?*	
006	I have learnt new thing and I am very interested in how chemicals react	LEUN/60/006 TINT/60/006
007	*The subject matter relates to life outside the classroom?*	
008	Knowledge of acids and bases is important to life outside the classroom. The knowledge of compounds is also important	RLST/60/008
009	*This course is different t any other I have done in junior school?*	
010	This course was similar to the elements course in Year 8 but there is a lot more explanation of why things happen	TEEX/60/010
011	*Any other comments on the unit Compounds*	
112	I have no comments except that it was very interesting	TINT/60/112

STUDENT NUMBER: 061

001	*The work in this class is too easy/too hard?*	
002	The work isn't too easy or too hard	TLJR/61/002
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004	I spend as much time	TSSA/61/004
005	*I have/have not learned anything new in this course and I am bored?*	
006	I have learned new things and I am not bored	LEUN/61/006
007	*The subject matter relates to life outside the classroom?*	
008	Some of it does	RLLI/61/008
009	*This course is different t any other I have done in junior school?*	
010	We do things in more detail	TLDT/61/010
011	*Any other comments on the unit Compounds*	
112	We should do LOTS of practical work	COMP/61/112

STUDENT NUMBER: 062

001	*The work in this class is too easy/too hard?*	
002	Medium	TLJR/62/002
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004	I do	TSSA/62/004
005	*I have/have not learned anything new in this course and I am bored?*	
006	Have	LEUN/62/005
007	*The subject matter relates to life outside the classroom?*	
008	No, at this stage we don't use these chemical compounds	RLNO/62/008
009	*This course is different t any other I have done in junior school?*	
010	It is similar to last years course but in more depth	TLDP/62/010
011	*Any other comments on the unit Compounds*	
112	More fun experiments	COMP/62/112

STUDENT NUMBER: 063

001	*The work in this class is too easy/too hard?*	
002	Some easy, some hard. I had trouble with some concepts at first but I understand them now	TLCH/63/002
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004	Just as much time on my schoolwork, but it sparked more other interest. See also 6	TINT/63/004 TSSA/63/004
005	*I have/have not learned anything new in this course and I am bored?*	
006	Chemistry is certainly not my favorite part of science but nevertheless I was not bored. See also 6	TINT/63/006
007	*The subject matter relates to life outside the classroom?*	

008	It has , and I know about household chemistry a bit more	RLST/63/008
009	*This course is different t any other I have done in junior school?*	
010	It is similar in subject and approach to the one I did in Year 8…but I'd never done an experiment at home before!	COMP/63/010
011	*Any other comments on the unit Compounds*	
112	Both my parents and I have commented on how the compound assignment has changed my outlook on science. Sometimes it was a bore finding a compound everyday (especially when I was tired and coming home late), but now I talk to Dad about science and get New Scientist when I can. I can also instantly recognize compounds in current affairs	COMA/63/112 RLST/63/112 TINT/63/112 COMR/63/112

STUDENT NUMBER: 064

001	*The work in this class is too easy/too hard?*	
002	I was absent for one week and missed a lot of work which has been difficult to catch up on, but the unit has not been too hard apart from that.	LEUN/64/002
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004	I spend a similar amount of time as my other subject and a similar amount to science last year	TINT/64/004
005	*I have/have not learned anything new in this course and I am bored?*	
006	I have learned a lot of new things in this course and have not been bored	TINT/64006
007	*The subject matter relates to life outside the classroom?*	
008	The subject covered does relate some what to everyday life, but may be more useful in the future	RLST/64/008
009	*This course is different t any other I have done in junior school?*	
010	This course has been similar but covered more information than other junior science	TLDT/64/010
011	*Any other comments on the unit Compounds*	
112	It has been a very interesting topic but could have possibly had more pracs	TINT/64/112 COMP/64/112

STUDENT NUMBER: 065

001	*The work in this class is too easy/too hard?*	
002	I feel the work is about right	TLJR/65/001
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004	I spend as much time now if not a bit more	TSMO/65/004
005	*I have/have not learned anything new in this course and I am bored?*	
006	I have learned a lot of new things and I'm <u>not bored</u>	TINT/65/006
007	*The subject matter relates to life outside the classroom?*	
008	I feel that most does but that some is so complicated that it is irrelevant	RLST/65/008
009	*This course is different t any other I have done in junior school?*	
010	Yes There are a lot more extra pieces of work outside the normal work which I didn't do last year	COMP/65/010

011	*Any other comments on the unit Compounds*	
112	It is fairly complicated and it took me some time to grasp some of the ideas	LEUN/65/112

STUDENT NUMBER: 066

001	*The work in this class is too easy/too hard?*	
002	Mostly fairly easy	TLTE/66/002
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004	I do	TSSA/66/004
005	*I have/have not learned anything new in this course and I am bored?*	
006	I have	
007	*The subject matter relates to life outside the classroom?*	
008	No. There is not much use for chemistry outside class	RLNO/66/008
009	*This course is different t any other I have done in junior school?*	
010	A bit more depth in what we learn. Otherwise the same	TLDP/66/010
011	*Any other comments on the unit Compounds*	
112	Should be fewer assignments	COMA/66/112

STUDENT NUMBER: 067

001	*The work in this class is too easy/too hard?*	
002	I find this class is just right as it is not too easy and not too hard	TLJR/67/002
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004	I have put in the same amount of work this year as I had last year	TSSA/67/004
005	*I have/have not learned anything new in this course and I am bored?*	
006	I have learnt something new	LEUN/67/006
007	*The subject matter relates to life outside the classroom?*	
008	Yes	RLST/67/008
009	*This course is different t any other I have done in junior school?*	
010	No	TSMA/67/010
011	*Any other comments on the unit Compounds*	
112	We have learnt some of the stuff last year on compounds	TSAM/67/112

STUDENT NUMBER: 068

001	*The work in this class is too easy/too hard?*	
002	The work in this class is not too easy and not too hard but is challenging	TLJR/68/002 LEUN/68/002
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004	I do	TSSA/68/004
005	*I have/have not learned anything new in this course and I am bored?*	
006	I have learned many new things in this course	

007	*The subject matter relates to life outside the classroom?*	
008	Yes	RLST/68/008
009	*This course is different t any other I have done in junior school?*	
010	No. Really different	TSAM/68/010
011	*Any other comments on the unit Compounds*	
112	I'm glad we got given the outcome slip at the beginning of the year	TEOR/68/112

STUDENT NUMBER: 069

001	*The work in this class is too easy/too hard?*	
002	It is mild, although I would like a little more repetition of instructions - a sheet perhaps	TEOR/69/002
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004	Not really, In fact spend more time <u>in depth</u>	TSMO/69/004
005	*I have/have not learned anything new in this course and I am bored?*	
006	I have learned new things, but sometimes I keep forgetting the basics because we're getting into more and more practical and complex exercises. So a jog of memory now and again would help	LEUN/69/006
007	*The subject matter relates to life outside the classroom?*	
008	Yes it does especially the experiments and assignments	RLST/69/008
009	*This course is different t any other I have done in junior school?*	
010	Slightly although only marginally. If you the library search it's practically the same.	COMR/69/010
011	*Any other comments on the unit Compounds*	
112	No	

STUDENT NUMBER: 070

001	*The work in this class is too easy/too hard?*	
002	OK	TLJR/70/002
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004	It' the same	TSSA/70/004
005	*I have/have not learned anything new in this course and I am bored?*	
006	I have but I am bored	LEUN/70/006
007	*The subject matter relates to life outside the classroom?*	
008	Yes	RLST/70/008
009	*This course is different t any other I have done in junior school?*	
010	Yes	

011	*Any other comments on the unit Compounds*	
112	No	

STUDENT NUMBER: 071

001	*The work in this class is too easy/too hard?*	
002	Too easy	TLTE/71/002
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004	I can't remember	TSNM/71/004
005	*I have/have not learned anything new in this course and I am bored?*	
006	I have not learned much and I am bored	TBOR/71/006
007	*The subject matter relates to life outside the classroom?*	
008	Yes it does	RLST/71/008
009	*This course is different t any other I have done in junior school?*	
010	No it isn't	
011	*Any other comments on the unit Compounds*	
112	Less repetition in naming compounds	TREP/71/112

STUDENT NUMBER: 072

001	*The work in this class is too easy/too hard?*	
002	I found the work in this class a little too fast, not too easy and too hard	TLJR/72/002
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004	I have put in as much work as in Year 8	TSSA/72/004
005	*I have/have not learned anything new in this course and I am bored?*	
006	I have learned many things continued from my previous areas of science	LEUN/72/006
007	*The subject matter relates to life outside the classroom?*	
008	Yes it does	RLST/72/008
009	*This course is different t any other I have done in junior school?*	
010	No	
011	*Any other comments on the unit Compounds*	
112	This topic is a very interesting one. I had enjoyed learning chemistry	TINT/72/112

STUDENT NUMBER: 073

001	*The work in this class is too easy/too hard?*	
002	The work in this class is neither too easy nor too hard. It's just right for my liking	TLJR/73/002
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004	I do not spend as much time doing normal homework but for things like studying and assignments I spend as much or more time	TSMO/73/004
005	*I have/have not learned anything new in this course and I am bored?*	

006	I most certainly have learned things in this course and I have never found science boring	TINT/73/006
007	*The subject matter relates to life outside the classroom?*	
008	The course relates to outside life as much as you would expect to. Chemistry does relate to outside life a fair bit, but not as much as other areas might	RLST/73/008
009	*This course is different t any other I have done in junior school?*	
010	Not particularly. It is harder and more interesting but that seems to happen every year	TINT/73/010
011	*Any other comments on the unit Compounds*	
112	All of the practical stuff is fun	COMP/73/112

STUDENT NUMBER: 074

001	*The work in this class is too easy/too hard?*	
002	The work that we do in class is neither too hard or too easy but it is very competitive	LEUN/74/002 TCOM/74/002
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004	Not really	TSSA/74/004
005	*I have/have not learned anything new in this course and I am bored?*	
006	I have learned new things in the course I am not bored	TINT/74/006
007	*The subject matter relates to life outside the classroom?*	
008	Yes, such as experiments at home and assignments to broaden my view	RLST/74/008
009	*This course is different t any other I have done in junior school?*	
010	This course is different, as we have done a lot of library research, which we didn't in Year 8. This class is also more competitive	COMR/74/010
011	*Any other comments on the unit Compounds*	
112		

STUDENT NUMBER: 075

001	*The work in this class is too easy/too hard?*	
002	I have found that such work as writing chemical formulae is too easy but things such as the pH scale is a little more stimulating	TLTE/75/002 TLCH/75/002
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004	I haven't spent as much time on science as I did in Year 8 because most of the compounds work was just revision from last year	TSNM/75/004
005	*I have/have not learned anything new in this course and I am bored?*	
006	At the start of the term it was boring because it was revision from work last year but towards the end it became practical and interesting	TBOR/75/006 COMP/75/006 TINT/75/006
007	*The subject matter relates to life outside the classroom?*	

008	So far, the work doesn't seem to relate to life outside the classroom	RLNO/75/008
009	*This course is different t any other I have done in junior school?*	
010	This course is different to any other chemistry course because we have learned <u>why</u> and <u>how</u> things are rather than just <u>wha</u>t happens	TEEX/75/010
011	*Any other comments on the unit Compounds*	
112	The assignment wasn't particularly good and not useful in studying or learning. The pracs need to be more exciting and dangerous	COMA/75/112 COMP/75/112

STUDENT NUMBER: 076

001	*The work in this class is too easy/too hard?*	
002	All right	TLJR/76/002
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004	I do	TSMO/76/004
005	*I have/have not learned anything new in this course and I am bored?*	
006	I am not bored	TINT/76/006
007	*The subject matter relates to life outside the classroom?*	
008	Nor really	RLNO/76/008
009	*This course is different t any other I have done in junior school?*	
010	Yes, I find very informative	LEUN/76/010
011	*Any other comments on the unit Compounds*	
112	No	

STUDENT NUMBER: 077

001	*The work in this class is too easy/too hard?*	
002	As there have been a lot of different concepts to grasp some people would obviously have more trouble than others. For me a lot of it was a bit easy, however I did find some of it hard	TLCH/77/002
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004	I have not spent as much time on science this year as I had in previous years	TSNM/77/004
005	*I have/have not learned anything new in this course and I am bored?*	
006	I have found some parts of this course very interesting, however some of it was a review of Year 8 work and I found it a bit boring	TINT/77/006 TBOR/77/006
007	*The subject matter relates to life outside the classroom?*	
008	To this stage I have found very little use for this work outside the room	RLNO/77/008
009	*This course is different t any other I have done in junior school?*	
010	This course has been different to other chemistry courses as we have had more use and done more prac experiments, rather than straight learning	COMP/77/010
011	*Any other comments on the unit Compounds*	
112	The whole unit was dragged out a bit long	TBOR/77/112

STUDENT NUMBER: 078

001	*The work in this class is too easy/too hard?*	
002	OK classwork was reasonable	TLJR/78/002
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004	I do	TSSA/78/004
005	*I have/have not learned anything new in this course and I am bored?*	
006	No I am not bored. I enjoy chemistry so I found the unit very interesting	TINT/78/006
007	*The subject matter relates to life outside the classroom?*	
008	Acids and bases in everyday life	RLST/78/008
009	*This course is different t any other I have done in junior school?*	
010	Yes	
011	*Any other comments on the unit Compounds*	
112		

STUDENT NUMBER: 079

001	*The work in this class is too easy/too hard?*	
002	Neither	TLJR79/002
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004	I do not	TSNM/79/004
005	*I have/have not learned anything new in this course and I am bored?*	
006	I have learned	
007	*The subject matter relates to life outside the classroom?*	
008	No	RLNO/79/008
009	*This course is different t any other I have done in junior school?*	
010	Not really	TSAM/79/010
011	*Any other comments on the unit Compounds*	
112	More experiments please!	COMP/79/112

STUDENT NUMBER: 080

001	*The work in this class is too easy/too hard?*	
002	No, It is alright because all the difficult things were well explained	TEEX/80/002 LEUN/80/002
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004	I spend more time on science than in Year 8 because there is slightly more work	TSMO/80/004
005	*I have/have not learned anything new in this course and I am bored?*	
006	I have learnt a lot of things and I am definitely not bored	TINT/80/006
007	*The subject matter relates to life outside the classroom?*	
008	Yes. A lot of things	RLST/80/008

009	*This course is different t any other I have done in junior school?*	
010	No, there is a small differences and that is extra work	TSAM/80/010
011	*Any other comments on the unit Compounds*	
112	It is an interesting topic and more should be studied	TINT/80/112

STUDENT NUMBER: 81

001	*The work in this class is too easy/too hard?*	
002	Fairly easy except for one or two points, electron dot formulas, ionic and covalent bonds.	TLJR/81/002
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004	Less due to less homework and the fact that I rarely bother to revise the days work for any subject unless there is a test coming. Like soon for science	TSNM/81/004
005	*I have/have not learned anything new in this course and I am bored?*	
006	I have learned new stuff but a lot I already knew.	LEUN/81/006
007	*The subject matter relates to life outside the classroom?*	
008	Don't know, I don't look at things in that way	RLNO/81/008
009	*This course is different t any other I have done in junior school?*	
010	It's pretty similar to some extra curricula science camps I have done	TSAM/81/010
011	*Any other comments on the unit Compounds*	
112	Writing out endless lists of answers for formula writing NaF, sodium fluoride is very boring after the first 5 or so	TBOR/81/112

STUDENT NUMBER: 082

001	*The work in this class is too easy/too hard?*	
002	The work can be quite easy, this is when it is explained thoroughly and we understand it, if not it can be quite confusing	TEXP/82/002 TLJR/82/002
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004	I spend a little less on science and more on my weaker subjects	TSNM/82/004
005	*I have/have not learned anything new in this course and I am bored?*	
006	I have	LEUN/82/006
007	*The subject matter relates to life outside the classroom?*	
008		RLNO/82/008
009	*This course is different t any other I have done in junior school?*	
010	This course has been different to other chemistry courses as we have had more use and done more prac experiments, rather than straight learning	COMP/82/010
011	*Any other comments on the unit Compounds*	
112	The whole unit was dragged out a bit long	TBOR/82/112

STUDENT NUMBER: 083

001	*The work in this class is too easy/too hard?*	
002		
003	*I found that compared to my other subjects I do/do not spend as much time on science as I did in Year 8*	
004		
005	*I have/have not learned anything new in this course and I am bored?*	
006		
007	*The subject matter relates to life outside the classroom?*	
008		
009	*This course is different t any other I have done in junior school?*	
010		
011	*Any other comments on the unit Compounds*	
112		

Appendix D2

Two Year 9 analogies assignments transcribed in full, student 093 and student 101.

9S1 ANALOGIES ASSIGNMENT

Student: 93

Line Number	Text
	Part A
	(a)
0001	(i) (i) The earth is like a giant onion made of
0002	layers of peel
0003	(ii) The plates are like giant pieces of a jigsaw
0004	puzzle that don't quite fit together
0005	(iii) Superposition is like a large storage box -
	the most recent items can be found at the
	top while the oldest items are at the
0006	bottom
0007	
0008	(b)
0009	(i) This analogy allows people to not only
0010	look at the core of the earth but instead the
0011	entire planet as even the atmosphere is
0012	made of layers. What is not suggested or
0013	stated here is how some layers are linked
0014	or how the layers vary in size or density.
0015	By thinking of the Earth as a series of
0016	layers we also understand how everything
0017	fits together including the different layers
0018	of rocks. An onion is something very easy
0019	to visualize and to complement the entire
0020	analogy; it is shaped like the Earth.
0021	(ii) I could not think of a better way to of
0022	summarizing how the plates fit together.
0023	Although the analogy fails to suggest or
0024	state that the plates move about slowly

0025		and drift. With a jigsaw puzzle should two
0026		pieces not neatly fit they will overlap in
0027		places and in other places they might have
0028		a gap. Another failure or weakness in the
0029		analogy is that is it does not show how the
0030		'pieces' may rub against each other (as if
0031		the puzzle-solver is trying to force them to
0032		fit) with sometimes-catastrophic
		consequences such as earthquakes or
0033		volcanoes.
0034	(iii)	Although it is not the best way of
0035		describing what superposition is, this
0036		analogy shows why layers are at the
0037		bottom are older. The largest fault with
0038		this analogy is the fact that the box can be
0039		used again, arranged, or rearranged with
0040		the order of objects being changed.
0041		Perhaps it would have been better to have
0042		chosen a 'skip bin' (large bin workmen use
0043		from depositing broken rock when
0044		building/renovation a house, etc…). As
0045		this would have not only incorporated the
0046		earth but is something that would not be
		rearranged. It does make something that
		can be understand easily, even by young
0047		(er) people.
0048		
0049	(c)	*Note: I feel this topic has also been*
0050		*covered in part (b) however I will try to*
0051		*add new information.*
0052	(i)	The onion is an accurate way of
0053		understanding how most geological
0054		structures are made of layers. It allows us

0055	to visualize the layout and manner in
0056	which layers exist with one another.
0057	(ii) The tectonic plates are a large part of
0058	geology and while the analogy of the
0059	jigsaw puzzle does not apply to any other
0060	geological concepts, it can be understood
0061	at all levels of learning and education.
0062	(iii) In geology rocks are always placed
0063	according to the law of superposition.
0064	This law is also the basis for examining an
0065	area and while it is not the best of the
0066	analogies I came across, it does
0067	demonstrate, in a logical way, why the
0068	rocks are at the bottom are older than
0069	those at the top.
	PART B
0070	(a) Erosion is like the carpenter who slowly sands
0071	down a wooden surface.
0072	(b) This analogy allows a person to understand
0073	the basic concept of erosion and weathering
0074	and other forces that can reshape the
0075	landscape in a similar manner. It is a very
0076	limiting analogy especially when used to
0077	describe geological concepts. A large part of
0078	the analogy is how it is succinct and simple, if
0079	it was revised and maybe more accurate, it
0080	would not flow as smoothly and would be less
0081	'poetic' to some degree.
0082	(c) Perhaps the largest problem with using the
0083	carpenter and the sandpaper is the image
0093	conjured up almost immediately is that
00101	smoothness. In reality the results of erosion

0086	and weathering slowly reshape a rocky
0087	surface, they act just like the sandpaper as
0089	particles of rocks are broken off slowly
0090	wearing down the surface. These agents can
0091	take many, many years before they make
0092	really noticeable changes unlike the carpenter
0093	who finishes often in a number of hours. After
0095	enough particles have been removed from the
0096	original rock the result is not only a smaller
0097	rock but also one that has been reshaped. And
0098	what of the sawdust and wood shavings? In
0099	reality wind or water transport and deposit the
0100	broken particles and fragments and deposits
0101	them elsewhere as sediments, usually in a
0102	river or the sea.
0103	(d) To give the full story: The wood-craftsman
0104	takes his piece of wood and begins to sand it
0105	into shape. As he sands the wood slowly
0106	changes shape and cracks begin to form. The
0107	sawdust is brushed off and falls into the dust-
0108	box. Should the wood-craftsman continue to
0109	sand his wood would eventually disappear.

Student: 101

Section 1

It is important, in order to understand how various concepts and phenomena work, to liken them to other things, or occurrences. If we can comprehend the intricacies and details of this other (usually more common, or simpler) occurrence, we can then liken it to a more complicated or abstract one, which then takes on a greater level of meaning for us. We have created an analogy.

Analogy 1

"The earth is like a custard"

This analogy says that when the earth was formed, it was like fresh hot custard in a bowl. When the custard was left for a while, it can be observed that a "skin" forms over the surface. This is akin to the gradual cooling of the earth from its original molten state, from the outside inwards. If the custard is left to cool for longer the "skin" will become thicker, and cracks will appear. These sections of "skin" will begin to float around on the still hot underneath part of the custard. The custard would slowly cool until finally it would become solid. This analogy describes the way that the earth formed in terms of cooling, and can be used to predict future changes to the earth (that is, that the earth will very slowly cool until it is entirely solid). This analogy also helps to describe the theory of plate tectonics. The small sections of custard "skin" floating on the surface of the still hot custard are similar to plates, and they float because of the of the convection currents, like their real equivalent.

Although this analogy shows very well the way that the earth has cooled (from the crust inwards) and even helps to explain tectonic plates and their movements, it has some faults. The bowl of custard dose not gives an idea of the spherical shape of the real earth. It does not provide an adequate model of the earth in terms of the mantel, core, etc… although the crust is represented fairly well. The custard itself also does not really represent the incredibly complex mixture of elements in the earth.

This model is very effective in developing my geological understanding because it is very easy to visualize, and it seems to have several parts that seem to correspond to real life very well. For the concept it tries to explain \, it does an extremely good job. However, if applied to certain other concepts, such as the complexity of the earth, it is not quite as useful.

Analogy 2

"The earth is like a Swede turnip".

The spherical shape of the Swede turnip is similar to the approximately spherical; shape of the earth. However the main correlation one can make with Swede turnip and earth is when the turnip is cut in cross section. The external layer of the turnip represents the crust of the earth. As one looks a little below the surface layer on the cross-section it is possible to compare this part with the mantle of the earth. Closer to the core of the turnip, there are layers, which can be compared to the earth. The core itself is similar to the center of the earth. This analogy helps to develop the concept of the earth's layered interior. Students can study this as a model of the inside of the earth.

He purpose of the model is purely to attempt to teach the internal structure of the earth. It also does not convey any idea of the earth cooling, so it does not give the idea of an active earth.

For the purposes of teaching the internal structure of the earth is not too great detail, it is fairly effective. However, it is not quite as effective if 4applied to other concepts such as the changes in the earth over time.

Analogy 3

"Layers of rock in the earth are like layers of colored plasticine".

This analogy says that the layers of different rock in the earth's crust undergo processes that can be simulated by layers of plasticine of different colors (which represent the different rocks). When several layers of plasticine are laid down one on top of the other, they begin to look a little like the layers of the earth. If one then bends this model, it takes the appearance of folded rock layers in the earth's crust. If a part is then cut off the top of the bend so that an anticline is produces; the resulting shape could be compared to an unconformity, or a weathered part of the rocks. A cut inn the plasticine can be compared to a fault in real layered rock.

This model helps to teach that layers of rock are laid down horizontally, and about various processes that can change the shape of rock layers under the earth's surface. It may also help develop the concept of a layered crust, and assist students with the idea of a geological history.

This model, however, does not give any indication about the heat and other forces inside the earth. The "laying down" of the plasticine layers gives no idea of the amount of time taken for these processes to occur in the real earth, and it does not show the progressive deposition and compaction that creates these layers.

This model is effective in teaching the theory that strata are deposited in horizontal layers, as well as informing the student about various aspects of strata formation, such as folding, weathering and faulting. Like the other analogies, it cannot be applied to concepts other than that it is explaining.

SECTION B

"Layers of rocks at a fault zone are like steps on an escalator".

This analogy explains the way that the strata slip up and down against each other when a fault occurs. Escalator steps slide up and down smoothly as in a real fault zone in the earth's crust. The layers, that is, the edge of the steps, are exposed when the slippage occurs.

This analogy also helps me to understand the principle of subduction of plates in plate tectonics. This can be seen when the top steps of the escalator slide beneath the floor above.

Escalator steps are like layers of rock in a fault zone after slippage, because the steps slide up and down against each other. However the analogy is different to the phenomenon of a real fault, because of several reasons. For example escalator step "faults" are always straight and regular, whereas in real life, faults can be different in shape, for example bent or jagged. Also further layers can form. Also the "plates" do not really ever meet, and there is no uplifting of the surface.

To address the deficiencies of this analogy, its various parts must be dealt with individually. A further analogy could be that of outdoor patio tiles sitting on a sandy surface. If someone steps on the tile, it may tilt, so that the edge moves further down in the sand. This "fault" could be bent or jagged, depending on the angle and strength of the forces applied, just like in real life. Sandy sediment could also build up on top of the tile that has been pushed down. However, the tile is still not layered like real strata.

Patio tiles can also be used to represent the tectonic plate section of the first analogy. The tiles can move apart, slide against each other, or subduct, and the top tile would be pushed up. These are all processes that occur with tectonic plates. In this analogy, of course, the "plates" do meet, and "react" to one another, unlike those in the first analogy.

So we can see that when an analogy is created, although it is usually useful in explaining the concepts that it sets out to teach, it does not necessarily explain everything.

Appendix D3

Twenty-five 9S1 (1997) students' diary entries transcribed

Appendix D3

Note: The student numbering was altered during the writing of this thesis and so is not sequential. Line numbering is sequential.

Transcription of 9S1 Analogy Diary entries 1997

Line No and student number	Diary entry
001 034 002 003 004	We have used analogies to 1.Describe particles e.g. sand and hundreds and thousands 2. To explain atoms e.g. models
005 006 007 008 009	The use of models to describe how to name compounds showed me how they fit together and helped me to understand a bit. The jigsaw model is a bit confusing because some compounds you could not make though
010 042 011 012 013 014 015 016 017 018 019	So far in science we have used analogies in Adding volumes- hundreds and thousands mixed with sand compared to water and methylated spirits The atom- like a solid ball, plum pudding etc The electron in comparison to the nucleus- if the nucleus was a golf ball in the middle of the oval, the electrons would be in the car park The electron circuit- the path the electron runs on is like a shell
020 021 022 023 024 025 026	The use of model most definitely increased my understanding of naming compounds because it actually shows each part of the compounds. It especially helped me with the valences of the radicals. It also helped me to name compounds as it made it a lot more simple than looking at a bunch of numbers
027 028 029 030 031	Hundreds and thousands with sand to explain methylated spirits and water. The analogy of an atom started as a sphere, then a plum pudding model and then the nucleus with surrounding electrons
032 033 034 035	I did not do this analogy but in general models help to explain whatever the model is trying to explain. The reason for this is to think back to a model than a writer thing
02 036 037	Analogies we have used so far… The sand and hundreds and thousands to explain the methylated

038 039 040	spirits and water Our model of our atom is what we use to explain the properties of chemicals
041 042 043 044	The use of a model was useful in visualizing the compounds and it made it easier to decide which elements or ions would go together. It helped with valency e.g. barium nitrate
03 046 047 048 049 050	Plum pudding model of an atom Mixing hundreds and thousands and sand Golf ball in a sports stadium Using models of atoms to create model compounds
051 052 053 054	Did the use of models increase my understanding of naming compounds? It didn't help me because I already knew from last year when we did a chemistry unit
04 055 056 057	Plum pudding Golf ball in a football stadium Hundreds and thousands and sand
07 058 059 060 061 062 063	The analogy Hundreds and thousands - meths and water experiment Desks in the room- ion electron configuration Size of a city - atoms as the size of hundreds and thousands for one jar of water
064 065 066 067	Using models A model was used to represent compounds. It increased my understanding of how valencies work in compounds forming
068 055 069 070 071 072	So far we have used analogy in describing the way two elements can mix (hundreds of thousands with sand) compared to methylated spirits and water. Another is the way atoms are organized, as in the plum pudding model
073 074 075 076 077 078 079	I believe that the model increased my knowledge of many compounds because it found that not all the non-metals and polyatomic ions can be used with all metals and the number of these that can be used with each metal is specific. I had a vague idea that this was the way it worked, but this confirmed what I thought.
080 …….037 081 082	100's and 1000's with sand to represent water with methylated spirits The atom (verbal analogy) Describing a model of an atom

083 084 085 086	Jigsaw puzzle for compounds The use of a model did help my understanding of naming compounds because it helped me visualize how compounds can form
087 ……039 088 089 090 091	We have used an analogy to describe the way two different size particles fit in the gaps of the other particles. The plum pudding model was used to describe a model of an atom
092 093 094 095 096	The use of a model increased my understanding of naming compounds because it allowed me to actually "see" how the atoms were joined together. For example, the jigsaw allowed me to see how the compounds came together.
097 056 098 099 100 101 102	Analogies are used commonly to describe models in chemistry Hundreds and thousands- molecular compounds Golf ball in a football field, Plumb pudding, Basket ball size, Marshmallows in Australia- Atomic model
103 104 105 106	Model of ionization. Yes this model helped me to visualize the connection of elements between each other in a compound, because of the symbolic nature that the model presents
107 040 108 109 110 111 112	We've used analogy in chemistry when we likened the hundreds and thousands and sand with methylated particles mixed with water particles. We've used it to explain through discussion the atom model
113 114 115 116 117 118	Yes, the model did increase my understanding of naming compounds. A visual picture is easy to remember and recognize. The model was simple to construct gave us a better understanding of which elements could react together and which couldn't
119 041 120 121 122 123	We've used hundreds and thousands to explain the mixing of water and metho to show that volumes are not necessarily additive. We've also discussed the model/structure of an atom; verbally
124 125 126	The use of a model did increase my understanding of naming compounds because I can visualize how it works how 2 or more elements or polyatomic ions join up. It was very easy to

	understand with the use of puzzles
…043	A science analogy is showing you something you know and comparing it with something you are not sure about, e.g. showing 100's and 1000's with sand and how the sand particles are smaller and fit between the 100's and 1000's and comparing it with methylated spirits and water and how the metho particles are smaller than the water and when you add them e.g. 50mL and 50mL you would get about 97mL and not 100mL
	The use of the model didn't really increase my understanding because I kind of knew how to name compounds, but naming it off the models was easier than looking up the valencies
…044	We used hundreds and thousands and sand as a model for methylated spirits and water. We wanted to show how and why, when water and methylated spirits are mixed less than the usual amount of volume is left.
	I did not understand about the combining of ions and +'s and -'s but the models let me understand
……..045	Analogies we have used so far- model for an atom scaled block of a metal, hundreds and thousands to sand/water and methylated spirits. Analogies are when you jigsaw puzzle atom
046	100's and 1000's experiment - like metho and water The atom molecule models Electrons travel in a shell The distance between the electron shells and the nucleus
	The use of the model compounds did help me to understand their naming. If you join two hydrogens to one oxygen then it is easy to see that the formula is H_2O
…….047	The plum pudding model Golf ball = nucleus, electrons = football stadium in car park Hundreds and thousands and sand
	The use of a model my understanding of naming compounds, as now I have a picture idea and clearer thought of how compounds are formed valency wise

170	
171…….049 172 173 174	Hundreds and thousands The atom models Electrons like a shell The distance of the electrons from the nucleus
175 176 177 178	The use of a model I think would help because it provides a visual picture which would make the information easier to locate and remember (I didn't get the model)
179…….036 180 181 182 183 184	Analogy-used to compare something Hundreds and thousands, sand as atoms in a measuring cylinder Fruit plum pudding to describe the atom Golf ball inside football field atom Marshmallows on Australia
185 186 187	Yes, it helped me because it shows what could/could not go together to help me understand compounds
188 ….. 051 189 190 191	We used analogies during the 'adding volumes' experiment, by using hundreds and thousands and sand to simulate mixing methylated spirits and water
192 193 194	The use of this model increased my understanding of naming compounds because it visualized how compounds are joined
195……050 196 197	Model of atoms (verbal) Hundreds and thousands with sand to represent water with methylated spirits
198 199 200 201 202	The models did help us understand the compounds better because we could visualize which elements could react together and which couldn't. But some elements that could fit together were not possible
203…..052 204 205 206 207	The model of methylated spirits and water using sand and hundreds and thousands. Blocks of metals if they were as big as hundreds and thousands they'd be as big as a city. How atoms are organized, the plum pudding model
208 209 210 211	The use of a model did increase my understanding of naming compounds because the concept of making a full rectangle was easier to grasp.
212 …….053 213	100's and 1000's with sand to represent water and methylated spirits.

214	The atom (verbal) to represent a real atom
215 216 217 218 219 220 221	The use of models to represent compounds and how they are put/combined together by valencies has greatly increased my understanding of naming compounds, because the model does not fit then the compound will not exist, and if it does fit then naming the compound is easy as you can see clearly what it is made of.
222 …. 054 221 222 223 224 225 226	Analogies that are commonly used to describe models in chemistry Hundreds and thousands Golf ball football field Plum pudding Basket ball size Marshmallows in Australia
227 228 229 210	This model helped me to visualize the connection of elements between each other in a compound, because of the symbolic nature that the models present.

Appendix D4

Three transcribed interviews with Year 10 and Year 11 students, students 40, 93 and 101

YEAR 10 INTERVIEW

Student 93

Teacher:	Do you remember last year you did your assignment on analogy.
Student:	Oh, I remember that.
Teacher:	Yeah.
Student:	Very vaguely.
Teacher:	This is what we're talking about. Right. Now if you remember, there were two parts, I haven't got it bound at the moment, there were two parts to the exercise. One was can you recognise analogies in text and to me from the answers that I got, everybody had no trouble, once they had worked out what an analogy was and recognised it in text and the second part was creating your own analogy. And that's probably where I'm going to focus most of my questions today. Can you remember that analogy?
Student:	Um, the analogy I gave **(reading from text can't quite understand)**. Oh, yes I remember typing that.
Teacher:	Can you describe the analogy to me?
Student:	Um, as in just talk about off the top my head? Alright at the time they were based very much on things we found on the internet. I was just talking to Shaun at the time about it, for some strange reason a lot of the analogies put it towards the work of someone else or some sort of inanimate object. And so a rodent something we studied probably a few days earlier, um and I think I had a woodwork assignment so at the time it was good. So the erosion when we were sanding down a piece of wood bit by bit for particles the

	wood came off as sawdust slowly came off and sanded down until it got smaller and smaller and if you changed the shape altogether which was similar to the patterns of erosion caused by wind or water.
Teacher:	It was a nice analogy. Did the exercise of creating the analogy, did you find it difficult?
Student:	Yes. But more so finding an analogy which sounded good, I mean the example we found in the textbook made a lot of sense, it was very easy to understand. So to try and make one which was just as simple without making a three sentence analogy was probably the hardest part.
Teacher:	So, what did you think about it as an exercise. Creating your own analogy? In actually coming to terms with the content that we were doing?
Student:	The hardest part was understanding part A of the assignment which was actually what the analogy was and when we could finally understand what the analogy was find how to pick it up in some other source, then creating one wasn't so hard, but you had to have background knowledge.
Teacher:	But you had more problems with the first part? Can you remember?
Student:	Yes, the I think the hardest part was when we were actually given the assignment sheet and just looking at it, it almost made no sense and the entire class had to ask questions and see some example. I think the sheet about one example on it. Oh, it didn't have any. I think you gave us one example first.
Teacher:	I think so.
Student:	That it made it a little clearer and you actually

	pointed out a couple from the textbook and explained them and once you explained everything fitted into place.
Teacher:	So, you really want to work analogies in your textbook in your reading before that exercise?
Student:	I suppose you saw it but it was more subconscious, it wasn't something which just stared out as an analogy it was just something that helped you read the text. I suppose it makes it easier to visualise something.
Teacher:	Have you seen this thing and recognise anything?
Student:	Yes. And probably a lot more easily. I suppose there's always been visual aid you just didn't realise they were there so much.
Teacher:	Have you developed any of your own analogies since?
Student:	Yes. Definitely. Especially when it comes to learning subjects when you have to study for a test you have an assignment coming up.
Teacher:	Can you give me an example?
Student:	Oh, science, science where it was used the most. Um and earlier in the year we had an electricity assignment coming up and someone just could not get their head around what was happening in the diagram and the easiest way to look at it was to show them that it was like cars and traffic lights and that you could just simply show that the car drove out of the negative and came around and had to stop at the traffic lights when it was open, when it was closed again it could continue to travel through back to the positive. Then they showed there was a whole line continuously going.

Teacher: Okay, so where did you get that analogy from? It just came up?

Student: Just came up.

Teacher: Good. If you were to develop, I didn't ask this question, if you were to develop an analogy how would you go about it?

Student: I don't know. I think if I were to develop an analogy I just think of something and someone would ask it to be explained or I wouldn't be able to explain it and I'd just think of something. I wouldn't structure it or formulate it, it's just something that you suddenly think of.

Teacher: With the analogy that you've got of the cars with the electricity do you still think of the electricity as the cars or if you drop the analogy because you just understand what's going on?

Student: Funnily enough, half the time I drop, half the time I think I even see it as water at one stage, just flowing water you could turn on and off pipes and in the test we did earlier this week, at one stage we had to sort the diagrams and I actually did at one stage I had to think oh hang on it would be flowing out of here and it would stop here, you had to actually look at it although I understand the concept in my head, when I actually had to sort through it, it was easier to relate it to a simpler concept.

Teacher: This is coming back to learning. Are you aware of any technique that will help you remember things in class.

Student: Mnemonics works sometimes, or something similar. In electricity again, I think that's the hardest topic I found this year. I just remembered

	PETPVC the formulas so when I wrote it on the paper I could write P = ET and then P = V/C And the first time I went into the exam I wrote PVC at the top of the test and somehow that was just helping me remember the formulas.
Teacher:	How do you remember, have you though about it?
Student:	It probably depends if you like the subject enough you just make waves or you just know and if you dislike the subject or you have a lot of trouble with it you probably go through and look for something to make it easier and you just keep trying to memorise the mneumonic or analogy of the device so if that’s clear in your head in an exam situation it’s going to be much easier to remember the mneumonic and let that lead on to the rest of the information.
Teacher:	Are you aware of the sorts of things that you remember best in science?
Student:	Um, I think it heavily depends on the topic. I am not that good at geology and as a result I have to work a lot harder at it, although I enjoy electricity as a hobby. When it actually came to formulas I had to work a lot harder at it. So it just completely depends on the topic as to how you have to go about it.
Teacher:	So, can you remember a lesson that stands out in class as one where you actually think of as " gosh"?
Student:	I suppose whenever you do an experiment it makes life a lot easier because it’s not remembering something from the text book, you’re actually see it in action and so when we were study complete combustion you had I

suppose a pyrotechnics display where he showed incomplete combustion, complete combustion, you saw the different chemicals, you saw how they reacted, because of the fire, because of the noise, it just made it a lot easier to remember what happens to different types of combustion.

Teacher: Okay. It's actually linking together there. What do you think this says about this sort of learning?

Student: What I just described?

Teacher: Mmm.

Student: Probably the lesson is different, that it stands out because you did an experiment, you did an activity, you didn't take notes or watch a video. It's probably more likely to stick in your mind. Then if you remember loosely that day you are more likely to remember what happens in it and so in the test you think oh I remember what we did that day, or I remember how that works.

Teacher: What's the sorts of things that you hang on to? You know when you are remembering. So if something stuff you learn for a test. What sorts of things do you keep remembering?

Student: Anything which is very new, anything that I found new, humorous, or strange or indirect sticks. Okay I enjoy electricity but probably everything I've learned this year will have gone out of my head. Like in evolution which I didn't enjoy as much when you looked at some of the different theories for dinosaur extinction, the thing with the eggs, when we saw the different ways people see evolution and the religious debates, while it wasn't my favourite topic, I just found that very interesting, everyone's different

	point of view and I’m much more likely to remember that five years from now.

YEAR 10 INTERVIEW

Student 101

Teacher:	Last year you did this assignment on analogies, I haven’t got it bound, it’s just there. If you remember the first part of the exercise was identifying analogies in textbooks to see whether you could identify analogies, and the second was to get you to develop your own analogy. Do you remember the analogy?
Student:	I think so.
Teacher:	Do you want a quick look at it and see if you can remember it.
Student:	Yes, I think I remember this one.
Teacher:	Okay, well what I would like you to do is to briefly describe it to me.
Student:	Okay. This analogy is that layers of rock at a fault zone are like the steps on an escalator and this explains the way that the strata in the earth slip up and down against each other when the fault occurs in an escalator the stairs when it reaches the top or bottom, move together, or move apart and that simulates in some ways a normal fault.
Teacher:	Okay, how much trouble did you have in actually coming up with that analogy?
Student:	Um, I had a bit of trouble actually I tried to think of

	several concepts to find analogies to, but a lot of them had already been mentioned in the text book or the two similar to other analogies and to find a good analogy that actually explains as much as possible as truthfully as possible is difficult. This doesn’t explain everything obviously. It does have deficiencies.
Teacher:	With the first section we did where you were actually identifying the analogies in the text book, had you seen or recognised these as analogies before the exercise?
Student:	You mean like the earth is like a swede turnip
Teacher:	Yeah, yeah.
Student:	Yes, actually because the whole concept of the earth being like a swede turnip unless you take it as an analogy, it’s somewhat ridiculous. But as an analogy you can learn from it.
Teacher:	Were you aware, I was going to say even in your other reading that you’ve done in science of how many analogies there are around?
Student:	I think most of the time I’ve tried to look at the analogies done. I guess in all cases I haven’t looked into the analogy to see just how far they go to show the exact truth of the concept.
Teacher:	Okay. Have your developed any of your analogies yet?
Student:	Nothing, nothing formalised I think I haven’t thought of anything specific. If I went away and thought about it for a while I might think of something, nothing I can.
Teacher:	Okay, if you had to develop an analogy, how would you go about it?
Student:	Probably, I’d first start off by looking at the concept that I like to develop an analogy for and maybe a

	concept that I needed an analogy to remember certain information. You know technical, all this type of information and maybe after that I'd attempt to think of something which was similar to it. I might go through a list of things that are more closely. But a lot of things can be used as an analogy without them being entirely correct. Maybe they're just correct for one part of the concept but not all of them.
Teacher:	If you did develop an analogy, at times you may have developed an analogy, do you think that you would keep using the analogy or would there get to a time or a point where you drop the analogy because you actually know?
Student:	I think an analogy would always be helpful in remembering something. I mean perhaps I know something well, but unless I was constantly going over it, which I have to say isn't my tendency to do, an analogy would be a good way of making sure that I'd always remember it and possibly also a good way of relating to other parts of the same concept, if something new came up.
Teacher:	Can I go back to this exercise that you did here, in retrospect, if you were trying to get an exercise to get students to think, did it achieve that end?
Student:	I think it did yes because I certainly had to think about, a correct analogy to use as well as looking through my text book and so on to find a good analogy.
Teacher:	Well I thought it was a nice example.
Student:	Very useful.
Teacher:	Are you aware of any techniques that help you remember ideas or concepts?
Student:	Apart from analogies?

Teacher:	Yes.
Student:	Well not necessarily in science but remembering lists, things, you can think of that, what's the term for when you have a word …
Teacher:	Mneumonic?
Student:	That's the one. For example, the rainbow, often useful for remembering the order of things for example the order of things in the light spectrum. And also there's the image way of remembering things where you imagine something in your mind with certain pieces of information you have to gather
Teacher:	What's an example?
Student:	What's an example? Well actually I learnt about this one in the study course and the example they had there was that if you had to remember a painting for example, that had an old woman and a chair that was painted by a man named Whistler, you'd think of an old woman in the chair whistling and the more ridiculous the picture, the easier it would be for us to remember the information.
Teacher:	Do you ever use that in science?
Student:	Um, not in science as far as I know, maybe subconsciously when remembering some things depends.
Teacher:	How do you feel learning things for exams
Student:	I have to confess that I'm a bit of a crammer before exams I do a lot of revising and things, it depends what sort of material is in the test, often when a lot of analytical work is part of the test I don't need to study so much the information, but when there's a lot of information and processes to be learnt, like in carbon chemistry for example, often I do examples. I don't think I've actually used an analogy for a test up to this

	point, but it would be a good idea to remember.
Teacher:	I’m not saying you have to at all I’m just trying to get some idea about people’s thinking. Are you aware of the things you remember best in class?
Student:	Um, I think perhaps the things that I remember best are the things that have interest to me and that I pay most of the attention to like genetics for example. Dealing in ratios because it is of interest to me.
Teacher:	Okay, why?
Student:	I’m not actually sure.
Teacher:	The last one I’ve got here is what does this say about this sort of learning, so going back and not even the topic area a lesson is there a lesson that stands out for you?
Student:	Um, nothing that I can think of, actually something that I do remember, we didn’t actually do in science I did on work experience with a Science Educator, she at one stage was doing class on genetics and we did an experiment on extracting chromosomes from a pea plant which I found very interesting and have remembered and the things that she talked about were the same things we had done in class so that might have felt very important.
Teacher:	So what does this say about your learning? Have you ever thought about how you learn? What sort of learning you do.
Student:	I’m not sure. I find that if I concentrate and work through things I can learn long lists and bits of information so especially if they interest me, but often I find that I’m better with analytical type things. So I can work through them in my mind without needing to learn all the information.
Teacher:	So you’re able to run through it in your head. I need

to write them down, a similar process. That’s great. Thank you very much for that.

<u>YEAR 10 INTERVIEW</u>

<u>Student 104</u>

Teacher:	In Year 9 we did that unit on geology.
Student:	Yeah
Teacher:	And we developed an analogy for geology. Do you remember it at all?
Student:	Yeah we had that lady student teacher.
Teacher:	That's right. I'd forgotten that. That was a problem. Because I only picked the unit up at the end didn't I.
Student:	Yep.
Teacher:	Okay, so do you remember the unit that we did, the analogy paper that you wrote.
Student:	Yep.
Teacher:	Okay and in it you identified, right, what I was asking for was can you recognise analogies when you see them, once you know what you're looking for. Which was actually what the first part of the exercise was supposed to be doing and you didn't do that. Cause I remember when I looked at this the other day you didn't get such a particularly good mark
Student:	Yeah, I think I missed that one a bit.
Teacher:	Because you missed the first bit, but the second part was developing your own analogies. Can you remember doing that part of the assignment?
Student:	Yes, I think it was something about garbage bins.
Teacher:	That's right.
Student:	Yeah.

Teacher:	Did, developing that analogy help you to understand what was going on?
Student:	Um, I mean yes it did cause you put rubbish in the bin all the time and then because you move the rubbish about, like earthquakes, power moves and stuff.
Teacher:	It’s force though wasn’t it.
Student:	I imagine, I think maybe.
Teacher:	But when you go to the garbage bin,
Student:	You don’t look.
Teacher:	But do you now?
Student:	I couldn’t think, I thought I’d do it.
Teacher:	Yes, it’s a nice analogy I like the analogy. What I’m trying to do I think is to try with just an idea that just comes. You get an increased learning by actually thinking of the analogy. You have to sit down and think what is the position. What’s something that is like it and that particular thinking step involves a lot more effort than just reading a paragraph from a book. What do you think about that?
Student:	Well, yeah I mean cause when I did the analogy, I tried to think of what you do when you put down stuff and then when you put the older stuff on the bottom and I guess when you read a paragraph in the book, that’s' it, that’s all you get and then if you do an analogy you can think how I guess how they came up with, the scientists came up with the idea of superposition and how it relates back to the your life.
Teacher:	Do you think there are many problems with developing this sort of an analogy?

Student:	Oh, I think I said there weren't problems. Obviously.
Teacher:	Okay, go back as you the student trying to do this, did you find the exercise a positive exercise or just a negative one that you had to do?
Student:	I mean, I guess it was positive cause I remember it took me ages to think of analogy, something I could think of.
Teacher:	Were you happy with the analogy that you came up with?
Student:	Yeah, that's the only one, I mean I discussed it with someone else in class and what they were doing and that was the best I could come up with. I don't know what anyone else came up with.
Teacher:	I don't remember people coming up with garbage bin ones which was good. Have you developed any other analogy since that exercise in your life.
Student:	Um, yeah I guess when I studied to try to associate stuff, I try to create rhyming, something which brings back so you can remember terms and stuff. Analogies, um. Can't think of any.
Teacher:	Can you give me an example of something that you make a rhyme out of, that you've done this on.
Student:	I remember you're thinking about mitosis and meiosis,
Teacher:	Somebody remembered my anti
Student:	Anti yeah anticline
Teacher:	Sometimes I do when I'm trying to work out

	what compounds are I make models on the front bench to try explain things, you don't remember any of those do you?
Student:	No.
Teacher:	No? Okay, if you were going to develop an analogy how would you go about it?
Student:	Well for this thing I just, you gave it to us and then.
Teacher:	No I'm talking about now.
Student:	Now?
Teacher:	Now.
Student:	Um, I don't just look around you, that's what I usually do, I just look around and see what you do and then how it relates back to whatever science topic.
Teacher:	Have you got any other techniques you talked about trying to link, any other techniques that help you remember ideas or concepts in science
Student:	Um, I guess when I was learning electricity and, in electricity I Ohms Law because I did that radio test thing, we learnt that E is equal to IR and EIR is in alphabetical order that was easy and the equation for power is Watts equal E times I and there is a boy in Year 11 named Wei which is I just remember that. Um, yeah it's stuff like that how I just remember.
Teacher:	Okay, I remember Wei. What sorts of things do you remember best in class, ideas or concepts or is their a lesson in science that stands out as being one that you really relate to?
Student:	Not really, um. Oh I remember when we did

	pracs we didn’t always finish pracs in class, so it wasn’t always the best outcome, otherwise they were just all the same.
Teacher:	What about this year, nothing that stands out?
Student:	Oh, this year?
Teacher:	Yes.
Student:	Um, no not this year.
Teacher:	Go back is there nothing?
Student:	No, not really? Oh the science thing when we had the open day that was fun when we had all the displays that was interesting, cause we didn’t get to see that stuff in class.
Teacher:	Okay, so what do you think we can do to make science relate more to students
Student:	Um, I guess I’m interested in electricity, astronomy and those topics are not really covered at this school so, cause you know I’m not interested in geology, you know we do that here. So I guess if you can change the topics that might help a bit, that might be a big ask.
Teacher:	Okay. Why do you think we’re teaching the topics we are then?
Student:	Um, I guess that more people would relate, I mean I’m just like one person who likes electricity and then I maybe like the teacher arrangement there’s more teachers who taught geology or whatever, rather than teachers who want to teach electricity and electricity there is more pracs you have to do and that will take more time.
Teacher:	Okay, so you’ve got a student, obviously you’re a student, who likes this sort of astronomy and whatever, what does it say

about you as a learner, that you like.

Student: I only like the topics, I only enjoy learning about the topics I like.

Teacher: These are physics type topics you're talking about, they're very black and white, a lot of concrete or equation, relationships, do you like the pattern, what is it about the electricity that?

Student: I just find electricity is interesting because you know, because of computers and everything you just know what's going on. I mean people just say that this is a semi-conductive stuff and you pay outrageous money for stuff and it's all simple how they do it. It's all simple and it's just amazing how much people pay for stuff.

Appendix D5

Year 7 Yearly Examination. Electricity section transcribed with line numbers

Appendix D5

Year 7 Yearly examination (electricity section) transcribed

Name and line numbers	Examination and answers
Student 001	***1. (a) Pat and Rob made the following electric circuit using blocks of wood, metal drawing pins and metal paper clips for the switches, and a battery, a light globe and wires.*** ***They knew these two main rules about electricity:*** • ***Electricity travels through metals*** • ***Electricity must travel all the way around a circuit*** ***(i) If these rules are true, is the light on in this circuit? Yes/No*** No
001 002	The light is not on because the switches are in the wrong places
	(ii) An electric circuit like this is often used in light switches in homes, especially for hallways and stairs. What is this circuit designed to do?
003 004 005	It is designed so that when the first switch is on one of the wires you have to move the 2nd switch to the right wire for the light to turn on.
	2. Why do toasters and other electrical appliances include a fuse in their circuits?
006 007 008 009	Electric circuits have fuses in them that if there is a power surge or something like that the thin piece of wire melts opening the circuit preventing harmful damage to the person using the appliance.
	3 (a) Compare the readings on the two ammeters in the above circuit with a closed switch.
010 011 012 013 014	The readings on both ammeters would be the same because ammeters measure the flow of current through the circuit so the current in this circuit is the same all the way around therefore they both read the same.
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.
015 016 017 118 019 020 021	The explanation for the model above would be that: think of electrons flowing through the wire as coal trucks carrying energy when it reaches the light is lights up and the coal trucks keep on moving back to the cell for more energy all the while through that the electrons all move at the same speed therefore the ammeters will read the same.
	4. Look at the picture of Fred below. What two basic safety rules that Fred is ignoring?

022 023	He is not wearing rubber soled shoes and he's working with electricity around water.

Comments	Examination and answers
Student 002	***1. (a) Pat and Rob made the following electric circuit using blocks of wood, metal drawing pins and metal paper clips for the switches, and a battery, a light globe and wires.*** ***They knew these two main rules about electricity:*** • ***Electricity travels through metals*** • ***Electricity must travel all the way around a circuit*** ***(i) If these rules are true, is the light on in this circuit? Yes/No*** No
024 025 026	Because the electricity doesn't flow all around the circuits because the switch is to the right of the battery is turned off.
	(ii) An electric circuit like this is often used in light switches in homes, especially for hallways and stairs. What is this circuit designed to do?
027 028 029	The circuit is designed so whichever switch you turn on will complete the circuit and whichever switch you turn off will break the circuit.
	2. Why do toasters and other electrical appliances include a fuse in their circuits?
030 031	In case too much electricity is being used the fuse will melt and prevent the appliance from blowing up.
	3 (a) Compare the readings on the two ammeters in the above circuit with a closed switch.
032 033 034	The first ammeter would have a higher reading than the other one because the electricity has to go through the resistor which slows the current down
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.
035 036	The electricity has to go through the resistor which slows the current down.
	4. Look at the picture of Fred below. What two basic safety rules that Fred is ignoring?
037 038	Fred isn't wearing safety glasses and he shouldn't be using electrical appliances near water

Comments	Examination and answers
Student 003	***1. (a) Pat and Rob made the following electric circuit using blocks of wood, metal drawing pins and metal paper clips for the switches, and a battery, a light globe and wires.*** ***They knew these two main rules about electricity:*** • ***Electricity travels through metals*** • ***Electricity must travel all the way around a circuit*** ***(i) If these rules are true, is the light on in this circuit? Yes/No*** No
	There is no circuit here. That is, the positive and negative ends of the conductors do not join.
	(ii) An electric circuit like this is often used in light switches in homes, especially for hallways and stairs. What is this circuit designed to do?
	It's designed in parallel, that is so that if one goes out all the others still work
	2. Why do toasters and other electrical appliances include a fuse in their circuits?
	These include fuses so that if there is a short circuit, then the electricity will burn the fuse and not us.
	3 (a) Compare the readings on the two ammeters in the above circuit with a closed switch.
	They should not be the same because the circuit should not have an even number of electrons going through the circuit. One should be less, and one should be more.
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.
	This is so true because if the ammeters were the same then the battery would not run out, whereas, if the model I think is the correct one the battery will eventually run out
	4. Look at the picture of Fred below. What two basic safety rules that Fred is ignoring?
	(i) He is not wearing rubber soled shoes, if any at all (ii) (ii) He is working near a tap, which means water and electricity does not mix with water!

Comments	Examination and answers
Student 004	***1. (a) Pat and Rob made the following electric circuit using blocks of wood, metal drawing pins and metal paper clips for the switches, and a battery, a light globe and wires.*** ***They knew these two main rules about electricity:*** • ***Electricity travels through metals*** • ***Electricity must travel all the way around a circuit*** ***(i) If these rules are true, is the light on in this circuit? Yes/No*** No
057 058	One of the paper clips need to be turned so the circuit can be completed
	(ii) An electric circuit like this is often used in light switches in homes, especially for hallways and stairs. What is this circuit designed to do?
059 060 061	The circuit is designed so that when one light is turned on, the other doenn't turn off, and you can as many on/off as you want.
	2. Why do toasters and other electrical appliances include a fuse in their circuits?
062 063 064 065 066 067 068	Toasters and other electrical appliances include a fuse in their circuit so that ther wont be any chance of an elecricty overload destroying the appliances, and maybe the whole circuit of the house. The fuse works by if there is too much elecricity on the thin wire fuse it will brake, stopping the electricity getting through..
	3 (a) Compare the readings on the two ammeters in the above circuit with a closed switch.
069 070	The reading of the two ammeters should be exactly the same
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.
	4. Look at the picture of Fred below. What two basic safety rules that Fred is ignoring?
071 072 073 075 076 077 078	Firstly he should switch off the tap and mop away any water, because we know you should never mix water with electricity. Secondly he should wear some protection ie glasses and gloves. Thirdly he should be careful where he is drilling because he could hit an electric line

Comments	Examination and answers
Student 005	***1. (a) Pat and Rob made the following electric circuit using blocks of wood, metal drawing pins and metal paper clips for the switches, and a battery, a light globe and wires.*** ***They knew these two main rules about electricity:*** • ***Electricity travels through metals*** • ***Electricity must travel all the way around a circuit*** ***(i) If these rules are true, is the light on in this circuit? Yes/No*** No
079 080 081 082	The circuit is open and the light won't work. The switch on the right is not on the right pin. They know that electricity can't (travel) through wood either, so it still doesn't work.
	(ii) An electric circuit like this is often used in light switches in homes, especially for hallways and stairs. What is this circuit designed to do?
083 084 085	When one light is on the other lights don't have to be on but they can be on if you turn the switch for that light. This is called a parallel circuit.
	2. Why do toasters and other electrical appliances include a fuse in their circuits?
086 087 088 089 090 091	So if they overheat the circuit can be opened. This prevents the appliance from catching on fire when the wires have melted. When the wire gets to(o) hot it melts the fuse so it stops the circuit from continuing. The bad thing about this is that you have to change the fuse every time.
	3 (a) Compare the readings on the two ammeters in the above circuit with a closed switch.
092 093 094 095 096 097	The two ammeters readings would not be the same if the circuit was working. This is because the electricity would round left, across the switch and a bit of it would be used up if it went through the light. This would be the other way round if the circuit was running the other way.
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.
	4. Look at the picture of Fred below. What two basic safety rules that Fred is ignoring?
098 099 100 101	The first rule that Fred is ignoring is that he isn't wearing much safety gear. The only safety gear is the shirt. He should be wearing shoes, special glasses, gloves to protect his body. The second safety rule that Fred is breaking is that there is water near

102 103 104 106	the cord for the electric drill. Water and electricity don't mix. He should wipe up the water and turn off the tap.

Comments	Examination and answers
Student 006	***1. (a) Pat and Rob made the following electric circuit using blocks of wood, metal drawing pins and metal paper clips for the switches, and a battery, a light globe and wires.*** ***They knew these two main rules about electricity:*** • ***Electricity travels through metals*** • ***Electricity must travel all the way around a circuit*** ***(i) If these rules are true, is the light on in this circuit? Yes/No*** No
107 108 109	Because the drawing pin I have labelled 1 is connected to 2 and the number 2 is connected to number 4 and 4 is not connected to anything mental..
	(ii) An electric circuit like this is often used in light switches in homes, especially for hallways and stairs. What is this circuit designed to do?
110 111	This circuit is designed to make it able to switch your hallway/stair lights on from different switches
	2. Why do toasters and other electrical appliances include a fuse in their circuits?
112 113	They contain fuses so that the electricity can flow and heat the toaster
	3 (a) Compare the readings on the two ammeters in the above circuit with a closed switch.
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.
	4. Look at the picture of Fred below. What two basic safety rules that Fred is ignoring?
114 115 116 117	1. Fred should be wearing safety goggles while using an electric drill. 2. Fred should turn off the dripping water while using the drill or he may get electrocuted

Comments	Examination and answers
Student 007	***1. (a) Pat and Rob made the following electric circuit using blocks of wood, metal drawing pins and metal paper clips for the switches, and a battery, a light globe and wires.*** ***They knew these two main rules about electricity:*** • ***Electricity travels through metals*** • ***Electricity must travel all the way around a circuit*** ***(i) If these rules are true, is the light on in this circuit? Yes/No*** No
118 119 120	Because there is a break in the circuit. The current will flow from the battery, to switch, to a block of wood, which isn't a conductor.
	(ii) An electric circuit like this is often used in light switches in homes, especially for hallways and stairs. What is this circuit designed to do?
121 122	Light all lights simultaneously, and have two switches at which to turn the lights on or off.
	2. Why do toasters and other electrical appliances include a fuse in their circuits?
123 124 125 126 127	Because if there is a power surge, the fuse is so fine, that it breaks, it is like trying to fit 10 people through a doorway at once. With out the fuses there would be a power overload which can lead to fires in appliances.
	3 (a) Compare the readings on the two ammeters in the above circuit with a closed switch.
128	The two ammeters will have equal readings.
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.
129 130 131 132 133 134	The electrons which carry the electric charge move from the battery through the circuit, depositing their power charge at the bulb, before returning to the battery. Eventually running out of power to deposit, thus the battery goes flat. The ammeters only measure the electrons, not the amount of charge.
	4. Look at the picture of Fred below. What two basic safety rules that Fred is ignoring?
135 136	1. Never use an electrical appliance near water. 2. Always wear rubber soled shoes

Comments	Examination and answers
Student 008	***1. (a) Pat and Rob made the following electric circuit using blocks of wood, metal drawing pins and metal paper clips for the switches, and a battery, a light globe and wires.*** ***They knew these two main rules about electricity:*** • ***Electricity travels through metals*** • ***Electricity must travel all the way around a circuit*** ***(i) If these rules are true, is the light on in this circuit? Yes/No*** No
137 138	They have switch 1 with a tac leading off nothing, and this lead continues along the rest of the circuit
	(ii) An electric circuit like this is often used in light switches in homes, especially for hallways and stairs. What is this circuit designed to do?
	2. Why do toasters and other electrical appliances include a fuse in their circuits?
139 140 141	So that when it is used, if there is an electrical problem, the fuse will blow instead of the person getting electrocuted
	3 (a) Compare the readings on the two ammeters in the above circuit with a closed switch.
142	Both of the ammeters will read the same
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.
143 144 145	We connected the two ammeters in the circuit the same way as it is above. Even the most accurate ammeters in the world will measure the same
	4. Look at the picture of Fred below. What two basic safety rules that Fred is ignoring?
146 147 148 149 150	There is a tap on a water on the ground, and water and electricity should never be near each other. He has no shoes on. Because rubber soled shoes should always be worn so that electricity can Earth itself.

Comments	Examination and answers
Student 009	***1. (a) Pat and Rob made the following electric circuit using blocks of wood, metal drawing pins and metal paper clips for the switches, and a battery, a light globe and wires.*** ***They knew these two main rules about electricity:*** • ***Electricity travels through metals*** • ***Electricity must travel all the way around a circuit*** ***(i) If these rules are true, is the light on in this circuit? Yes/No*** No
	For the switch which is closest the lead or wire is not connected in the right places and the circuit is broken
	(ii) An electric circuit like this is often used in light switches in homes, especially for hallways and stairs. What is this circuit designed to do?
	This circuit is designed to light the globe which probably is used for a lamp or a signal carrier.
	2. Why do toasters and other electrical appliances include a fuse in their circuits?
	Electrical appliances includefuses so that if there is an overload or a short circuit the fuse is able to burn out so the electricity does not earth or go through you.
	3 (a) Compare the readings on the two ammeters in the above circuit with a closed switch.
	We connected the two ammeters in the circuit the same way as it is above. Even the most accurate ammeters in the world will measure the same
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.
	From the battery electrons carrying energy go through the ammeter. The ammeter measures how many electrons pass. It goes through the switch and drops off the energy in the bulb. It goes through the ammeter with the same reading as the first one and goes back to the battery.
	4. Look at the picture of Fred below. What two basic safety rules that Fred is ignoring?
	Do not use electrical appliances near running or just water Wear safety equipment Leave electrical problems to electricians Wear rubber soles in case of shock

Comments	Examination and answers
Student 010	***1. (a) Pat and Rob made the following electric circuit using blocks of wood, metal drawing pins and metal paper clips for the switches, and a battery, a light globe and wires.*** ***They knew these two main rules about electricity:*** • ***Electricity travels through metals*** • ***Electricity must travel all the way around a circuit*** ***(i) If these rules are true, is the light on in this circuit? Yes/No*** No
173 174	The light is not on because the switches go to different wires ie like this
	(ii) An electric circuit like this is often used in light switches in homes, especially for hallways and stairs. What is this circuit designed to do?
175 176 177 178	Allow you to use either switches to turn on the light because one is one way and the other the light will be off but if some one changes on switch it will turn on
	2. Why do toasters and other electrical appliances include a fuse in their circuits?
179 180 181	Some electrical appliances often have fuses so that if an overload occurs the fuse will break opening the circuit and giving us safety
	3 (a) Compare the readings on the two ammeters in the above circuit with a closed switch.
182 183 184 185	The 2 ammeters on the above switch will show the same as the particles aren't depleted but the energy they carry to the light is, so both ammeters will show the same amps going in different directions.
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.
186 187 188 189 190	The ammeter count particles, (amps) so each particle is carrying a store of energy which means that when they get to the light something happens and that is that they give their energy to the light and go back to the battery.
	4. Look at the picture of Fred below. What two basic safety rules that Fred is ignoring?
191 192 193	The 2 basic safety rules Fred is ignoring is 1. Never have water near wires and 2. Always wear insulated clothing

Comments	Examination and answers
Student 011	***1. (a) Pat and Rob made the following electric circuit using blocks of wood, metal drawing pins and metal paper clips for the switches, and a battery, a light globe and wires.*** ***They knew these two main rules about electricity:*** • ***Electricity travels through metals*** • ***Electricity must travel all the way around a circuit*** ***(i) If these rules are true, is the light on in this circuit? Yes/No*** No
	From the battery to the switch it is connected but electricity only goes through metal so it cannot get to the next switch which carries a wire to the light
	(ii) An electric circuit like this is often used in light switches in homes, especially for hallways and stairs. What is this circuit designed to do?
	This is a series circuit. It is designed to turn on all lights (which in this case is one) through the circuit.
	2. Why do toasters and other electrical appliances include a fuse in their circuits?
	Toasters and other electrical appliances have fuses so when there is too much electricity running through the fuse breaks, disconnecting the circuit. This is close to stop fires starting in a house. The fuse is thinner than other wire and thus breaks with more heat going through
	3 (a) Compare the readings on the two ammeters in the above circuit with a closed switch.
	With a closed switch the ammeters should have one reading more than the other the other being none. Ammeters measure amps which is the amount of energy in an electron.
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.
	The explanation is that the energy has been used up in the and the first ammeter still has amps in the circuit but the second one didn't.
	4. Look at the picture of Fred below. What two basic safety rules that Fred is ignoring?
	Fred should not have water on the floor nor a tap dripping in case a wire touches the water. He should also be wearing protective shoes and perhaps gloves.

Comments	Examination and answers
Student 012	***1. (a) Pat and Rob made the following electric circuit using blocks of wood, metal drawing pins and metal paper clips for the switches, and a battery, a light globe and wires.*** ***They knew these two main rules about electricity:*** • ***Electricity travels through metals*** • ***Electricity must travel all the way around a circuit*** ***(i) If these rules are true, is the light on in this circuit? Yes/No*** No
	Pat and Rod hadn't explained why electricity makes a light glow. Even though those two rules are true, the circuit is not closed to let electricity go through the whole circuit
	(ii) An electric circuit like this is often used in light switches in homes, especially for hallways and stairs. What is this circuit designed to do?
	This circuit can be for a light, which has 2 switches control the light. This can be used in a hallway where one switch is at one end of the hallway while the other switch is at the other end of the hallway.
	2. Why do toasters and other electrical appliances include a fuse in their circuits?
	Fuse is needed because if the wires of the toaster is getting too hot, the fuse will automatically burn up. With out the fuse the toaster may explode
	3 (a) Compare the readings on the two ammeters in the above circuit with a closed switch.
	The 2 ammeters will have the same reading
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.
	When electricity is flowing around a circuit, the speed and the amount should be the same
	4. Look at the picture of Fred below. What two basic safety rules that Fred is ignoring?
	1. There is water around him. NEVER have water around when you are dealing with electricity 2. He is not wearing safety glasses. ALWAYS wear safety clothes while using a dangerous tool.

Comments	Examination and answers
Student 013	***1. (a) Pat and Rob made the following electric circuit using blocks of wood, metal drawing pins and metal paper clips for the switches, and a battery, a light globe and wires.*** ***They knew these two main rules about electricity:*** • ***Electricity travels through metals*** • ***Electricity must travel all the way around a circuit*** ***(i) If these rules are true, is the light on in this circuit? Yes/No*** No
233 234 235	The current goes from the battery to the light, from the light to switch 1 Right from switch 1 right to switch 2 left, which is open.
	(ii) An electric circuit like this is often used in light switches in homes, especially for hallways and stairs. What is this circuit designed to do?
236 237 238	It is designed so that you have two switches (eg one upstairs and one down stairs) so you only need to switch one to turn off or on
	2. Why do toasters and other electrical appliances include a fuse in their circuits?
239 240	So that if the wire overheats the very thin wire will melt and will stop the circuit, so nothing can happen
	3 (a) Compare the readings on the two ammeters in the above circuit with a closed switch.
241 242 243	The readings will both be the same, because the current is flowing and gradually they will both go down.
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.
244 245 246 247 248 248 249	Electric current is not used up by the globes, the voltage is e.g. if you had 1 person for a globe and one person for the battery and the battery had a piece of paper the rest of the people were electrons. If the battery gave little pieces of paper as the people walked by and then gave it to the globe, the battery would soon run out.
	4. Look at the picture of Fred below. What two basic safety rules that Fred is ignoring?
250 251 252	He is ignoring the rule that says "were rubber soled shoes when working with electricity" and "electricity and water don't mix".

Comments	Examination and answers
Student 014	***1. (a) Pat and Rob made the following electric circuit using blocks of wood, metal drawing pins and metal paper clips for the switches, and a battery, a light globe and wires.*** ***They knew these two main rules about electricity:*** • ***Electricity travels through metals*** • ***Electricity must travel all the way around a circuit*** ***(i) If these rules are true, is the light on in this circuit? Yes/No*** No
	It isn't on because the circuit is not complete. This is because the two paper clips (switches) are not touching on the same wire. One paper clip is touching one drawing pin while the other is touching another pin. Therefore the circuit is incomplete and the light won't glow.
	(ii) An electric circuit like this is often used in light switches in homes, especially for hallways and stairs. What is this circuit designed to do?
	The circuit is designed so it starts off the way it is in the diagram and if someone switches it at one end of the hall, it makes a complete circuit and the light goes on. While the person at the other end of the hall can turn it off by making an incomplete circuit and they can continue to do this.
	2. Why do toasters and other electrical appliances include a fuse in their circuits?
	Toasters and other electrical appliances include fuses in there circuit , because if there was a power surge they would be damaged by excess current, but with fuses, if too much current tries to enter the circuit, the fuse will melt creating an open circuit to protect the appliance
	3 (a) Compare the readings on the two ammeters in the above circuit with a closed switch.
	The readings on the two ammeters with a closed circuit would be the same because the same current is going around the circuit, as an ammeter measures current.
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.
	My explanation is using model D and that the same amount of current goes into and out of the globe. This would not explain though, why a battery goes flat. Well it does, although the current is the same the amount of energy it is carrying is not, as it goes to the bulb it has a lot

	of energy as it comes out, it doesn't have as much energy. Which explains why the readings are the same.
	4. Look at the picture of Fred below. What two basic safety rules that Fred is ignoring?
	Fred is ignoring 2 basic safety rules, they are he is drilling into a wall with an electric drill with no shoes (rubber soles) if there was a short circuit he would be electrocuted. Another rule he is ignoring is that he is using electricity near water and water pipes and we know that water and electricity don't mix. So if the electricity came in contact with the water, he could be harmed or elecrocuted.

Comments	Examination and answers
Student 015	***1. (a) Pat and Rob made the following electric circuit using blocks of wood, metal drawing pins and metal paper clips for the switches, and a battery, a light globe and wires.*** ***They knew these two main rules about electricity:*** • ***Electricity travels through metals*** • ***Electricity must travel all the way around a circuit*** ***(i) If these rules are true, is the light on in this circuit? Yes/No*** No
	No because there is an open circuit. The circuit can not be completed because not all is connected. The switches have allowed to them to make an open circuit which is what they've done
	(ii) An electric circuit like this is often used in light switches in homes, especially for hallways and stairs. What is this circuit designed to do?
	The circuit is designed so one end can turn on and off and so can the other. The circuit is designed so people can have the power to make an open circuit using one switch
	2. Why do toasters and other electrical appliances include a fuse in their circuits?
	Toasters and other electrical appliances have a fuse because when there is a short circuit or a dangerous amount of electricity build up the fuse acts as a resistor and if too much electricity flows through it, it will melt causing an open circuit and makes sure so no one can get hurt.
	3 (a) Compare the readings on the two ammeters in the above circuit

	with a closed switch.
235	The readings on the ammeters are the same
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.
236	Amps stay the same during a circuit
	4. Look at the picture of Fred below. What two basic safety rules that Fred is ignoring?
237 238 239	Fred is working near water and Fred is also not wearing insulating shoes (rubber) which you should always do when working with electricity.

Comments	Examination and answers
Student 016	***1. (a) Pat and Rob made the following electric circuit using blocks of wood, metal drawing pins and metal paper clips for the switches, and a battery, a light globe and wires.*** ***They knew these two main rules about electricity:*** • ***Electricity travels through metals*** • ***Electricity must travel all the way around a circuit*** ***(i) If these rules are true, is the light on in this circuit? Yes/No*** No
240 241 242	This is because the circuit is not closed. This circuit has the switch turned off therefore the light will not light.
	(ii) An electric circuit like this is often used in light switches in homes, especially for hallways and stairs. What is this circuit designed to do?
243 244	This circuit is designed to be turned off and on at two different places.
	2. Why do toasters and other electrical appliances include a fuse in their circuits?
245 246 247	A fuse is used to ensure the safety of the people using this electrical appliance by melting or breaking if there is an electrical surge.
	3 (a) Compare the readings on the two ammeters in the above circuit with a closed switch.
248 249 250 251	The reading on both the ammeters should be the same and on the same side (positive or negative). This is because the bulb uses up volts and amps are just the current
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.
252 253 254	The reading on both the ammeters should be the same and on the same side (positive or negative). This is because the bulb uses up volts and amps are just the current

	4. Look at the picture of Fred below. What two basic safety rules that Fred is ignoring?
	Fred is working with a live power around a water source which can conduct electricity Fred is working near a small pond of water which can conduct electricity through him

Comments	Examination and answers
Student 017	***1. (a) Pat and Rob made the following electric circuit using blocks of wood, metal drawing pins and metal paper clips for the switches, and a battery, a light globe and wires.*** ***They knew these two main rules about electricity:*** • ***Electricity travels through metals*** • ***Electricity must travel all the way around a circuit*** ***(i) If these rules are true, is the light on in this circuit? Yes/No*** No
	Switch 1 now has directed the current to (A) of switch 2. However from A it can go no further because the switch is not connecting it from S2, the electricity goes to (R) of switch 1. But the switch 1 is not conecting it.
	(ii) An electric circuit like this is often used in light switches in homes, especially for hallways and stairs. What is this circuit designed to do?
	This circuit is designed for syairs and hallways in the reason that when you get to the top of the stairs you can switch it on and switch it off at the bottom and vice versa. This is the same as a hallway
	2. Why do toasters and other electrical appliances include a fuse in their circuits?
	In toaster, and after electrical appliances there is a fuse S6 that in times of powerload, the fuse will break and the circuit incomplete and the current will stop flowing. Or else if the fuse wasn't then it could blow up
	3 (a) Compare the readings on the two ammeters in the above circuit with a closed switch.
	The readings in the two ammeters should be equal because the volts are used up in the globe but the amount of current will stay the same. In class we used the analogy of trucks (amps) carrying coal (volts) to be burnt by the globe. The number of trucks coming back stayed the same but the number of coal differed.

	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.
	The ammeter readings stay the same but the number of volts differ. The current going through the ammeter is the same.
	4. Look at the picture of Fred below. What two basic safety rules that Fred is ignoring?
	Fred is ignoring the safety rules of, don't use an electrical appliance near water and to wear plastic soled shoes when working with electricity so that the electricity won't get you.

Comments	Examination and answers
Student 018	***1. (a) Pat and Rob made the following electric circuit using blocks of wood, metal drawing pins and metal paper clips for the switches, and a battery, a light globe and wires.*** ***They knew these two main rules about electricity:*** • ***Electricity travels through metals*** • ***Electricity must travel all the way around a circuit*** ***(i) If these rules are true, is the light on in this circuit? Yes/No*** No
	Though all wires are hooked up, the switch is not touching the wire which leads to the next switch which leads to the battery. Once the switch is turned to the right wire the light will be on.
	(ii) An electric circuit like this is often used in light switches in homes, especially for hallways and stairs. What is this circuit designed to do?
	It is designed to be switches on from on switch and switched off from the another switch
	2. Why do toasters and other electrical appliances include a fuse in their circuits?
	They include a fuse because if it doesn't , when it gets overheated the electricity will keep flowing creating a fire. When it has a fuse it can prevent a fire because the fuse will melt breaking the circuit when it gets hot.
	3 (a) Compare the readings on the two ammeters in the above circuit with a closed switch.
	The readings will be the same because the electrons will be equal on both sides.
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.
	The electrons will rub closely at the ammeters and the light , but, when

302 303	they come out of the resistor they are equal on both sides.
	4. Look at the picture of Fred below. What two basic safety rules that Fred is ignoring?
304 305 306 307 308	Fred is not wearing shoes and if the drill suddenly fall it may hurt Fred (if he falls on his feet). The water is left on and there is a little puddle. If Fred accidently steps into it he may faa over causing injury

Comments	Examination and answers
Student 019	***1. (a) Pat and Rob made the following electric circuit using blocks of wood, metal drawing pins and metal paper clips for the switches, and a battery, a light globe and wires.*** ***They knew these two main rules about electricity:*** • ***Electricity travels through metals*** • ***Electricity must travel all the way around a circuit*** ***(i) If these rules are true, is the light on in this circuit? Yes/No*** No
309 310 311 312	The light bulb is not on because the circuit isn't complete. As switch 1 (S1), the switch is fine but at S2, the switch is not at 4 therefore making it an open circuit. The light would be on if S1 was on 3
	(ii) An electric circuit like this is often used in light switches in homes, especially for hallways and stairs. What is this circuit designed to do?
313 314 315	The circuit is designed to be able to be turned onat one side of the stairs or hallway or at the other side of stairs or hallway
	2. Why do toasters and other electrical appliances include a fuse in their circuits?
316 317 318 319 310 311	Toasters and other electrical appliances have a fuse in their circuit, to stop the appliance from overloading. When the current running through an appliancegets too hot, the fuse burns up and breaks therefore making the circuit an open circuit. These fuses stop us from being electrocuted
	3 (a) Compare the readings on the two ammeters in the above circuit with a closed switch.
312 313 314 315 316	The two readings on the ammeters are different because A1 (refer to diagram) has more current (closer to the cells) than A2, A2 has less because the current has already gone through the battery. This means the current is less at A2.

	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.
	Current is a amount of power running through a circuit. At A1, the current is bigger than at A2 because at A1 the current has been through a light while at A2, the current has been through a light before making the current larger at A1 than at A2.
	4. Look at the picture of Fred below. What two basic safety rules that Fred is ignoring?
	Fred, has left the tap dripping so if he dropped the drill, it could electrocute him. Fred is not wearing any protective clothing so there is more chance of him being electrocuted. He should be wearing shoes, goggles, headwear, and better clothes.

Comments	Examination and answers
Student 020	***1. (a) Pat and Rob made the following electric circuit using blocks of wood, metal drawing pins and metal paper clips for the switches, and a battery, a light globe and wires.*** ***They knew these two main rules about electricity:*** • ***Electricity travels through metals*** • ***Electricity must travel all the way around a circuit*** ***(i) If these rules are true, is the light on in this circuit? Yes/No*** Yes
	This circuit will perform because everything is connected, this means that the circuit is closed and the bulb will light up
	(ii) An electric circuit like this is often used in light switches in homes, especially for hallways and stairs. What is this circuit designed to do?
	It is designed to be able to turn a light on and off at two different places, ie when you start in the hallway you can turn the light and when you get to the end, you can turn it off
	2. Why do toasters and other electrical appliances include a fuse in their circuits?
	A fuse is a safety object, and you cannot get electrocuted if, by accident, something goes wrong.
	3 (a) Compare the readings on the two ammeters in the above circuit with a closed switch.
	The two ammeters will show the same brightness and it will be very bright
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.

	4. Look at the picture of Fred below. What two basic safety rules that Fred is ignoring?
338 339 340 341	1. The tap is dripping out water and if the water is mixed with the electricity he will be electrocuted 2. There is a bare wire which could also electrocute him if he is not careful

Comments	Examination and answers
Student 021	***1. (a) Pat and Rob made the following electric circuit using blocks of wood, metal drawing pins and metal paper clips for the switches, and a battery, a light globe and wires.*** ***They knew these two main rules about electricity:*** • ***Electricity travels through metals*** • ***Electricity must travel all the way around a circuit*** ***(i) If these rules are true, is the light on in this circuit? Yes/No*** No
342 343	It is not complete. The switches are not completely joined together and joined to the wrong places
	(ii) An electric circuit like this is often used in light switches in homes, especially for hallways and stairs. What is this circuit designed to do?
344 345	This is designed so that if one light breaks, it won't affect the rest
	2. Why do toasters and other electrical appliances include a fuse in their circuits?
346 347	They have a fuse so that not too much power is passed through the appliance and damage it
	3 (a) Compare the readings on the two ammeters in the above circuit with a closed switch.
348 349	The ammeter on the left will have a higher reading because ther is a resistor between the two ammeters
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.
	4. Look at the picture of Fred below. What two basic safety rules that Fred is ignoring?
350 351	Fred is not wearing any footwear and has left the water running which makes it slippery and dangerous

Comments	Examination and answers
Student 022	***1. (a) Pat and Rob made the following electric circuit using blocks of wood, metal drawing pins and metal paper clips for the switches, and a battery, a light globe and wires.*** ***They knew these two main rules about electricity:*** • ***Electricity travels through metals*** • ***Electricity must travel all the way around a circuit*** ***(i) If these rules are true, is the light on in this circuit? Yes/No*** Yes
	Pat and Rob have made the switches with metal paper clips and metal drawing pins which will work fine. The electricity will flow all the way around because it is all wired up correctly depending if the switches are closed
	(ii) An electric circuit like this is often used in light switches in homes, especially for hallways and stairs. What is this circuit designed to do?
	This circuit is designed to be a parallel circuit so that when one light bulb goes out the other ones will stay on
	2. Why do toasters and other electrical appliances include a fuse in their circuits?
	Toasters and electrical applinces have fuses in their circuit because if it starts to overheat the fuse will overheat and when it starts overheating the fuse will go off and will change the circuit into an open circuit so it doesn't't' bring any harm to the user of the electrical appliances. Without the fuse and wires got overheated the user would get seriously injured and could possibly die.
	3 (a) Compare the readings on the two ammeters in the above circuit with a closed switch.
	The two ammeters will show an equal reading because as the electricity flows through both ammeters will be able to show the electricity flow through the bulb and cells. The way the two ammeters are positioned it will show the same reading.
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.
	We had a model a lot like the one above it was proven that there was an equal reading of the two ammeters. This was because of the electric flow that when through the bulb and the cells and then to the ammeter.

	4. Look at the picture of Fred below. What two basic safety rules that Fred is ignoring?
	One of the basic safety rules that Fred is ignoring the fact of eye protection. He is not bothering to wear safety glasses to protect his eyes and the tool he is using could cause you blindness if you weren't wearing any glasses. The other safety rule is that he is not noticing the fact that there is a puddle of water that he is standing very close to and he isn't wearing protective gear to prevent himself being electrocuted. He isn't even wearing and rubber soled shoes

Comments	Examination and answers
Student 023	***1. (a) Pat and Rob made the following electric circuit using blocks of wood, metal drawing pins and metal paper clips for the switches, and a battery, a light globe and wires.*** ***They knew these two main rules about electricity:*** • ***Electricity travels through metals*** • ***Electricity must travel all the way around a circuit*** ***(i) If these rules are true, is the light on in this circuit? Yes/No*** No
	It will not light up because the wire on S1 without the paper clip has got no electrons going through it. The other wire in S1 that goes to S2 goes nowhere, just to a dead end. The circuit is not complete
	(ii) An electric circuit like this is often used in light switches in homes, especially for hallways and stairs. What is this circuit designed to do?
	This is a parallel circuit which is designed to be very bright. It is also designed so that when one bulb goes out the others don't as in some other circuits
	2. Why do toasters and other electrical appliances include a fuse in their circuits?
	That is to give safety. What a fuse does is it stop the electricity to go through if there is too much current. If there is too much current the wires get extremely hot, melt and may be even cause a fire. We have fuses in our homes to prevent any accident of this. If the fuse does blow in an electrical appliance we need to tell a professional to fix it.
	3 (a) Compare the readings on the two ammeters in the above circuit with a closed switch.

	I think that the readings on both meters would be the same because the current would still be the same since I believe one of the models of electricity the have been presented.
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.
	The current would be the same using the explanation a model which says that the is the same current of the ammeter going out of a battery and after it has gone through the globe. The reason why the battery goes flat is only because the globe cannot use already used power.
	4. Look at the picture of Fred below. What two basic safety rules that Fred is ignoring?

Comments	Examination and answers
Student 024	***1. (a) Pat and Rob made the following electric circuit using blocks of wood, metal drawing pins and metal paper clips for the switches, and a battery, a light globe and wires.*** ***They knew these two main rules about electricity:*** • ***Electricity travels through metals*** • ***Electricity must travel all the way around a circuit*** ***(i) If these rules are true, is the light on in this circuit? Yes/No*** No
	The switch is touching the wrong drawing pin. If the switch was touching the other drawing pin then the circuit would be complete and glow, but now the circuit is incomplete
	(ii) An electric circuit like this is often used in light switches in homes, especially for hallways and stairs. What is this circuit designed to do?
	The circuit is designed so that there is a switch. This means that you can choose to have the light turned on or off.
	2. Why do toasters and other electrical appliances include a fuse in their circuits?
	Toasters have fuses because if they don't, too much electrical current can flow and can electrocute somebody. With a fuse, if too much electrical current flows, the fuse will break and no electricity will get through, and no-one will be hurt
	3 (a) Compare the readings on the two ammeters in the above circuit with a closed switch.
	The ammeters readings would be the same amount of amps, and going

	in the same direction towards the light bulb. That is according to one of the models discussed in class.
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.
	In class we developed a model that electricity flows to the battery through both leads at the same amount of amps. This explains why the battery runs out and it was proved possible with an ammeter.
	4. Look at the picture of Fred below. What two basic safety rules that Fred is ignoring?
	Fred is ignoring the fact that there is water around his feet and that there is also a tap. Fred is also not wearing goggles and this could ruin his eyes

Comments	Examination and answers
Student 025	***1. (a) Pat and Rob made the following electric circuit using blocks of wood, metal drawing pins and metal paper clips for the switches, and a battery, a light globe and wires.*** ***They knew these two main rules about electricity:*** • ***Electricity travels through metals*** • ***Electricity must travel all the way around a circuit*** ***(i) If these rules are true, is the light on in this circuit? Yes/No*** No
	On the second switch (shown) the clip should be on the other pin so electricity can go through the circuit
	(ii) An electric circuit like this is often used in light switches in homes, especially for hallways and stairs. What is this circuit designed to do?
	It is designed to give the elecricity more than one path, so if a light goes out, all the lights don't go out. This is called a parallel circuit
	2. Why do toasters and other electrical appliances include a fuse in their circuits?
	A fuse consists of a thin piece of wire, if there is too much electricity running through, then the piece of wire will become hot and melts creating an open circuit. This makes sure there a no overload in electrical circuits or appliances
	3 (a) Compare the readings on the two ammeters in the above circuit with a closed switch.
	Ammeter 1 would have more of a reading than ammeter 2 because electricity is running out of the battery into the ammeter. In ammeter 2 the electricity has go through a light bulb and this uses a lot of

	electricity.
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.
	4. Look at the picture of Fred below. What two basic safety rules that Fred is ignoring?
	Never mix electricty and water together Always wear rubber soled shoes when using electrical appliances

Comments	Examination and answers
Student 026	***1. (a) Pat and Rob made the following electric circuit using blocks of wood, metal drawing pins and metal paper clips for the switches, and a battery, a light globe and wires.*** ***They knew these two main rules about electricity:*** • ***Electricity travels through metals*** • ***Electricity must travel all the way around a circuit*** ***(i) If these rules are true, is the light on in this circuit? Yes/No*** No
	The switch first connected to the light bulb is alright, however the other switch is connecting to the wrong terminal and will not make a closed circuit. If either switch has its terminal changed the circuit will be closed
	(ii) An electric circuit like this is often used in light switches in homes, especially for hallways and stairs. What is this circuit designed to do?
	The circuit is designed to letr electricity pass through the switch then the light globe the back to the power source to create a complete circuit
	2. Why do toasters and other electrical appliances include a fuse in their circuits?
	A fuse prevents dangerous electrical accidents from occuring. When an electrical appliance draws too electricity the wires designed may become hot then melt, destroying the appliance and / or creating accidents. The fuse is a this piece of copper wire designed to melt before the accident occurs. Once the fuse melts the circuit is open therefore stopping the accident that may occur
	3 (a) Compare the readings on the two ammeters in the above circuit with a closed switch.
	The readings to the two ammeters will be the same. This is due to the

fact that the same amount of energy is flowing from both terminals to the battery.
(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.
Pieces of paper were passed from person to person (people being the wire) into the beam balance w(*h*)ere the weight was measured (ammeter) and the paper then the paper was passed through the little hole where the amount was limited accumulating to create light then the paper was measured on the beam balance and then returned back to the paper storage.
4. Look at the picture of Fred below. What two basic safety rules that Fred is ignoring?
The appliance is being used near a tap so if the wire is faulty. Fred will get electrocuted He should be wearing plastic soled shoes to prevent electrocution

Appendix D6

Year 8 electricity quiz, transcribed and coded

Appendix D6: Year 8 electricity quiz transcribed and coded

Name and line number	*Examination question and response*	Code
Student 001	*(a) Compare the readings on the two ammeters in the above circuit with the closed switch*	
008 009 010 011 012	The readings on both the ammeters will be the same because ammeters measure the flow of electrons in the circuit	MSAM/02/008
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.	
013 014 015 016 017 018	The scientific model that was developed that the electrons move through the circuit and the energy gets used in the light then the electrons move back to the battery.	RELE/02/013 RENE/02/016

Student 002	*(a) Compare the readings on the two ammeters in the above circuit with the closed switch*	
183	They are both the same.	MSAM/24/183
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.	
184 185 186 187 188	Everyone in the class walked around the room with a piece of paper. No one in the world has proved whether it was A, B, C, D or G	AANA/24/184 APAA/24/186 RLAY/24/188

Student 003	*(a) Compare the readings on the two ammeters in the above circuit with the closed switch*	
156 157	I think that both of the ammeters have the same amount of amps.	MSAM/20/156 VAMP/20/158

158		
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.	
159 160	I think that this model refers to model number no 4.	AANA/20/159 RLAY/20/160 AMOD/20/160

Student 004	*(a) Compare the readings on the two ammeters in the above circuit with the closed switch*	
058 059 060 061	The ammeter on the left will have a high reading, while the one on the right will be low.	 RHRE/09/058
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.	
062 063 064 065 066	Yeah, well the light bulb won't light up because the circuit is incomplete. We made one like the one above last year.	RLAY/09/062

Student 005	*(a) Compare the readings on the two ammeters in the above circuit with the closed switch*	
168 169 170 171	The two ammeters will be different. The one closest to the switch will be higher than the other one	MHRE/22/168
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.	
172	?	RUND/22/172

Student 007	*(a) Compare the readings on the two ammeters in the above circuit with the closed switch*	
173 174 175 176	Open=0 Closed: the two ammeters will be equal as it is wired in series and the current is not diverted or split	MSAM/23/173

177	anywhere.	
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.	
178 179 180 181 182	The current flows from the battery to the ammeter throughout the bulb to the ammeter and back to the battery.	RELE/23/178 VCUR/23/178

Student 008	*(a) Compare the readings on the two ammeters in the above circuit with the closed switch*	
067	The same reading will occur.	MSAM/10/067
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.	
068 069 070 071 072	The ammeters will have the same reading because not even the most powerful ammeter in the world could tell the difference.	RUND/10/068

Student 009	*(a) Compare the readings on the two ammeters in the above circuit with the closed switch*	
073 074 075 076	The first ammeter will have more higher reading than the 2nd ammeter (crossed out *the same reading)*	MHRE/11/073
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.	
077 078 079 080 081 082 083 084 085	The electrons are pushed by a force or volt and run through the ammeters. The ammeters read how many electrons are running through. The electrons then run into the light. After this they run back into the battery going through the ammeter.	VVOL/11/077 VAMP/11/079 RELE/11/082

Student 010	*(a) Compare the readings on the two ammeters in the above circuit with the closed switch*	
032 033 034 035	The two different ammeters will have the same readings as amps are not destroyed they just carry power.	MSAM/06/032
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.	
036 037 038 039 040 041 042 043	The two ammeters will show the same reading as the amps just carry power which is taken by the light to power it like dump trucks take the rubbish to the tip and then go and get some more rubbish etc etc	RELE/06/036 VAMP/06/038 VPOW/06/038 AANA/06/040 AOWN/06/040

Student 011	*(a) Compare the readings on the two ammeters in the above circuit with the closed switch*	
001 002 003 004	The readings on the ammeters should be the same as there is the same amount of electrons going through. It is a series circuit so current is not diverted	MSAM/01/001
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.	
005 006 007	When the circuit is closed electrons go through to the light and the electrons keep passing through.	RELE/01/005

Student 012	*(a) Compare the readings on the two ammeters in the above circuit with the closed switch*	
030 031	The two ammeters should have the same reading	MSAM/05/030
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.	
		RUND/05/031

Student 013	*(a) Compare the readings on the two ammeters in the above circuit with the closed switch*	
161 162	The readings will be the same	MSAM/21/161
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.	
163 164 165 166 167	The same amount of amps go out and the same amount go back in. The battery gives the amps energy and the amps give the energy to the light.	RELE/21/163 VAMP/21/163

Student 015	*(a) Compare the readings on the two ammeters in the above circuit with the closed switch*	
051 052	The ammeters would have the same reading	MSAM/08/051
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.	
053 054 055 056 057	The electrons travelling along the wires are not prevented in progress. The energy is returned to the battery	RELE/08/053

Student 016	*(a) Compare the readings on the two ammeters in the above circuit with the closed switch*	
086 087	The readings on the two ammeters are the same	MSAM/12/086
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.	
088 089 090 091 092 093	This circuit contains a light bulb, 2 ammeters and 2 batteries. The amps carry the volts to the battery but the amps themselves don't change.	RELE/12/088 VVOL/12/091 VAMP/12/092

Student 018	*(a) Compare the readings on the two ammeters in the above circuit with the closed switch*	
124	Both readings are the same.	MSAM/16/124
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.	
125 126 127 128 129	The electrons pass through the ammeter and resistor and the second ammeter. There is no light bulb to take up the electrons.	RELE/16/125

Student 019	*(a) Compare the readings on the two ammeters in the above circuit with the closed switch*	
140 141 142 143 144 145 146 147 148 149 150	The reading on A1 would be higher than on Q2 because some voltage would be lost when going through the light therefore, when turned on new, A1 would have full voltage but when it goes to A2, it would be lower because some voltage would be lost as it is needed to power the light.	MHRE/19/140
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.	
151 152 153 154 155	When the circuit is closed, the current goes from positive to negative. In this case, the large line to the smaller line.	RUND/19/151

Student 021	*(a) Compare the readings on the two ammeters in the above circuit with the closed switch*	
203	The ammeter on the right will have a	MHRE/26/203

204 205 206 207 208	higher reading because it is before the light while the ammeter on the left will have a lower reading because it is after the right	
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.	
209 210	When the switch is closed, the ammeter will ...	RUND/26/209

Student 022	*(a) Compare the readings on the two ammeters in the above circuit with the closed switch*	
120 121 122	In the circuit above the two ammeters will show the equal readings	MSAM/15/120
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.	
123	It is model B	AMOC/15/123 RLAY/15/123

Student 023	*(a) Compare the readings on the two ammeters in the above circuit with the closed switch*	
019 020	The ammeters would have the same reading	MSAM/03/019
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.	
021 022 023 024 025 026	There would be the same amount of electrons because there still is power going through after it was used in the bulb. It still has used energy	RELE/03/021 VPOW/03/024

Student 023A	*(a) Compare the readings on the two ammeters in the above circuit with the closed switch*	
027 028	Both ammeters show the same reading.	 MSAM/04/028

	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.	
029	Model used last year	RUND/04/029 RLAY/04/029

Student 024	*(a) Compare the readings on the two ammeters in the above circuit with the closed switch*	
113 114 115 116 117 118	The difference between the two readings of the ammeters is the same amount of electricity, but one reading is from the left and one from the right	MSAM/14/113
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.	
119	No answer	RUND/14/119

Student 025	*(a) Compare the readings on the two ammeters in the above circuit with the closed switch*	
044 045 046 047 048 049	Ammeter 1 will have a higher reading because electricity must go through a light globe to reach ammeter 2. Therefore ammeter 1 will have more.	MHRE/07/044
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.	
050	No answer	RUND/07/050

Student 026	*(a) Compare the readings on the two ammeters in the above circuit with the closed switch*	
094 095 096 097	The ammeters should have the same reading. The amount of electricity flowing through the ammeter on the right is how much electricity goes	MSAM/13/094 RELE/13/096

098 099 100 101 102	through the light bulb. The second ammeter shows how much is returning to the battery from the light bulb.	
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.	
103 104 105 106 107 108 109 110 111 112	Bits of paper are like electrons flowing in a wire. The first ammeter counts how many bits of paper goes to the light bulb and the light bulb is like a resistor which allows less paper to flow through. The second ammeter counts how much paper returns to the battery.	AANA/13/103 APAA/13/103

Student 027	*(a) Compare the readings on the two ammeters in the above circuit with the closed switch*	
130	None on either	MNON/17/130
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.	
131	Because the circuit is open	RUND/17/131

Student 028	*(a) Compare the readings on the two ammeters in the above circuit with the closed switch*	
132 133 134 135 136	The two ammeters should have the same reading, as there is nothing preventing the electricity from one over another.	MSAM/18/132
	(b) Explain your answer above using a scientifically accepted model of	

	electricity that you developed in class.	
137 138	The current travels along the wires and through the coil and into the bulbs.	RELE/18/137 VCUR/18/137

Student 029	*(a) Compare the readings on the two ammeters in the above circuit with the closed switch*	
189 190 191 192	The ammeter on the right will show a higher reading than on the ammeter on the left.	MHRE/25/189
	(b) Explain your answer above using a scientifically accepted model of electricity that you developed in class.	
193 194 195 196 197 198 199 200 201 202	Because the electrons travelling from the battery pass through the ammeter on the left before passing through the globe. The globe uses some electricity before letting the electrons through. The electrons pass through the left ammeter, thus resulting in a lower reading.	RALT/25/193

Appendix D7

Transcribed interviews with Year 9 students October 1999
(Year 7 1997)

Appendix D7: Transcribed interviews with Year 9 students (Year 7,1997)

Interview

Student 001

Date: 11 October 1999

Student number 001	
Interviewer	I have an open circuit here. If the circuit was closed can you compare the two readings on the ammeters.
Student 001:	Um (5 second pause)… This ammeter the first one would have …um,…if it was an open circuit.? Interviewer ”No it was closed circuit”…(5 second pause)
Student 001	They would both be the same”
Interviewer	OK, Can you explain how you got get that answer”?
Student 001	Because ammeters measure current and um it’s the energy that the current is carrying which is being used in the light bulb not the current itself and I can’t remember most of this stuff. ”
Interviewer	No that’s alright I am actually interested I your thinking as you go along. OK, in year 7 we developed an analogy for electricity that used a coal train”.
Student 001	Yes.
Interviewer	and we had people walking around with bits of paper. Can you remember it?
Student 001	Yes
Interviewer	OK, and can you explain to me what you remember about that analogy”?
Student 001	Um, the people were the electrons dropping off their energy at the light bulb, or what ever it was, and they kept on moving “.

Interviewer OK, did this analogy help you to explain how electricity works”.

Student 001 Uh yes.

Interviewer Can you explain how it helped?

Student 001 It was a model, any model helps, to show us how something works”

Interviewetr In this particular case can you think about how it helped explain what was going on?

Student 001 Um.. I can’t really explain how it helped, I know it helped

Interviewer Did it change your thinking at all/

Student 001 Um Yeah ah I just can’t explain it

Interviewer Ok Can you think of any problems with the analogy that we used?

Student 001 None that I know of

Interviewer Ok did you change the analogy at all in your head or did you just use it

Student 001 Yeah just the straight

Interviewer When you answered the question today did you use the analogy to help you answer it

Student 001 Yes

Interviewer Ok How

Student 001 I just remembered the model and sort of applied it to the situation

Interviewer When you started you were actually about to give me a different answer?

Student 001 Was I? What was I thinking?

Interviewer You actually stopped and thought and came up with the second answer

Student 001 Yes

Interviewer Do you remember what you were thinking at that time?

Student 001 Pause No Pause No I don’t remember

Interviewer Do you use any tricks or ways to help remember things in science?

Student 001 Um Models usually

Interviewer Visual models?

Student 001 Yes

Interviewer Can you explain an example where you would use a visual model?

Student 001 Um With the chemistry thing with all the electrons and different types of bonding and yeah

Interviewer So what sort of model is this? Is it like a solar model or a model where the nucleus is the sun...That sort of model ?

Student 001 Yes

Interviewer Are you aware of how you remember things

Student 001 No

Interviewer If you are trying to remember something how do you go about remembering it?

Student 001 Usually I just remember things. If I try to intentionally try to remember things it is usually by rote but I try not to do that because it usually doesn't stick when I'm trying to learn

Interviewer Ok So what sort of things would you use your rote learning for

Student 001 Oh vocabulary, and other things in language

Interviewer OK language, what about in science?

Student 001 Um most of the time I pick up first time round

Interviewer So you don't have to use any tricks or things to help you

096		Can you remember any time when you
097		didn't where you had to use something to
098		help you
099	Student 001	Only when I want to be really picky like
100		when we did the fossils thingy last year
101		and I memorized all the different time
102		periods
103	Interviewer	Ok
104	Student 001	But I didn't do that again as it took
105	me forever and I didn't find it useful	
106	Interviewer	Can you remember it now?
107	Student 001	No
108	Interviewer	No, what a pity
109		Are you aware of the sorts of things that
110	you remember best in science?	
111	Student 001	Yes. Things that I am interested in
112	Interviewer	Can you give me an example
113	Student 001	Chemistry, The stuff we did at the
114		beginning of this year and a bit of last year
115		and that just seemed very interesting and I
116		am able to understand that very well
117	Interviewer	So you didn't have any problems . A lot of
118		students with that Chemistry unit in Year
119		9
120	Student 001	I noticed that
122	Interviewer	My last question is What do you think this
123		says about the way you learn things or your
124		sort of learning
125	Student 001	I only learn really well on things I find
126		interesting or enjoy or um sort of like.
127	Interviewer	Are you the sort of person that remembers
128		lots of little detail or big pictures
129	Student 001	Lots of little details

Interviewer	OK so the detail appeals to you?
Student 001	Yes
Interviewer	And can you remember a lesson you have had recently that really appealed to you
Student 001	Um Not recently
Interviewer	Can you remember a lesson that you have had where you have had something, particularly in science because we are trying to focus on science if we can
Student 001	Yeah right at the beginning of the year in Chemistry cause until recently the stuff was quite dry and you can read the textbook and there is nothing really take with me Um Just the lesson where I realized how everything fits together
Interviewer	In the Chemistry again
Student 001	Yes
Interviewer	So what do you mean fits together?
Student 001	Um The way it all works um
Interviewer	Is that where you developed your model?
Student 001	Yes where I developed my model
Interviewer	And the model then held up in other things
Student 001	Yes
Interviewer	So did you test your model? How did you test your model?
Student 001	Um Well I used it in the test and I got it right I had no real way of being able to test that
Interviewer	OK but you be able to do it latter on when you do Chemistry
Student 001	Are we doing Chemistry next year
Interviewer	Yes and you will come against it there

Interview
Student 007

Date: 11 October 1999

Interviewer This relates back to the circuit that you have seen a number of times before. This is the battery, there is the bulb, and we've got the two ammeters here. at this stage it's an open circuit but if we close the circuit can you tell me what the readings would be like or compare the readings on the two ammeters, ammeter 1 and ammeter 2

Student 007 It would be the same. I don't think they would be the same

Interviewer Can you explain how you came to that result

Student 007 Um because the current doesn't actually change

Interviewer In Year 7 we developed an analogy for electricity as a coal train but what people do remember is the analogy where we stood up and did the role-play around the room. Can you explain to me the role-play or the analogy?

Student 007 Oh everyone came out like a battery or a light…(inaudible)…from the battery

Interviewer And what happened to them?

Student 007 And it got to the light bulb

Interviewer So what happened to the people holding it? Did they move or did they stay still

Student 007 They moved along

Interviewer Did this analogy help you at the time/ to explain how electricity worked or did you have it worked out before

Student 007 I think the different models helped

Interviewer Can you explain it at all how it helped you?

Student 007 I think we did the different models of how electricity worked , like the electricity went out of the battery and then when back in, or it changed or disappeared altogether that kind of thing

Interviewer Do you remember if there were any problems with the analogy when we did it?

Student 007 Uh no.

Interviewer Did you use the analogy at all to answer this here today or did you just know it?

Student 007 I didn’t think of it that way when you asked the question , I didn’t think of that

Interviewer No that’s all right, that’s what we are on about. When you are trying to learn something do you use any sort of “tricks”` or ways to help you to remember things in science

Student 007 Not really, unless they are given to me I don’t usually think of those things on my own

Interviewer So how do you learn?

Student 007 That’s a good question, probably rote, just reading it, just reading questions. By the time I’ve read something, read the questions, gone back and found the answer its pretty firmly stuck

Interviewer So how do you go about it, are there any other ways you go about remembering things

Student 007 Pause not hat I can think of , nothing conscious

Some of the boys were talking about chemistry were there any models you would use or ways you would remember things in chemistry. Did you have problems with the chemistry unit?

No I did pretty well in that , cause a lot of the chemistry I picked up last year and it wasn’t that hard

Interviewer So how did you go about learning your chemistry stuff? Was there any way, why did it stick for you?

Student 007 I guess it was just the way it was explained at the time

Interviewer You can’t remember the explanations?

Student 007 Oh no, things like valence and that kind of things like completing the shells so that it just needed extra electrons to complete the shell

Interviewer So what do you think of when they say “needing an extra electron” Do you have a picture in your head

Student 007 A circle with little dots on it I just remember it 8,8,16

Interviewer So it’s the nice pattern. What sorts of things do you remember best in science? Can you think of things that stand out, that were really easy to learn?

Student 007 Ah the chemistry was easy I suppose once you got the basic idea, once you got the basic idea of the shells and how they have to be completed all the rest comes, it just flowed on. At the time the electricity as it was easy

Interviewer So once you had twigged onto the pattern

Student 007 Okay, once the initial first steps click it was okay after that

Interviewer So are there any lessons that stand out for you in science as being lessons that appeal to the way that you learn best

Student 007 Oh yes the basic lessons

Interviewer Can you give me an example of a lesson that stands out

Student 007 Nothing really made much sense until you’ve got the basic groundwork

Interviewer Give me something that didn’t make sense to start with

Student 007 Didn’t make sense to start with pause that classification stuff cause I didn’t really learn how to classify initially and it didn’t make sense after that

Interviewer That’s interesting cause that is almost patterns when you look back

Student 007 I think it’s mainly cause I didn’t learn that initial stuff

	Interviewer What sort of learner do you think you are?
	Student 007 Do you mean like visual and that kind of thing?
	Interviewer Yes
	Student 007 Yes it's a lot easier if it's something I can see
	Interviewer So do you like lots of detail or do you like big pictures
	Student 007 It's easier to see it in the mind if there is a pattern. So that is what I find anyway
	Interviewer So when you are learning stuff at home do you just learn, you just do your reading, you don't draw pictures?
	Student 007 I just read it , take points out
	Interviewer So schooling has been fairly easy up to now, you have been able to slide through
	Student 007 Yes pretty much

Interview

Student 013

Date: 11 October 1999

First Language: English

Line number	Transcribed interview
	Interviewer If you remember this circuit we looked at in Year 7, we did lots of it in year 7 , this is our battery, this is our bulb and these are our ammeters. At the moment the circuit is open but if we close the circuit, can you compare the readings on the two ammeters
	Student 013 They would be the same
	Interviewer How did you get that result? What sort of thinking did you go through?
	Student 013 Amps go, they are the same, like the bulb doesn't use up the amps itself

Interviewer	In Year 7 we developed an analogy for electricity which used a coal train and we also did the role-play. Can you remember the role-play?
Student 013	Yes the paper
Interviewer	Can you explain it to me?
Student 013	Okay there was people giving out paper and there was a battery and everyone was walking around the classroom and there were two people and they were the light globe and they were taking in the paper and they were standing close together to be, so that the people would bunch up and they would go and get more paper and eventually the battery would run out of paper
Interviewer	Well done. Did this analogy help you to explain how electricity works?
Student 013	Yes
Interviewer	And can you explain how it helped you?
Student 013	I didn't know that that was how it worked I thought that it was just it was going out of the battery and yes a little was taken up and then there would be weaker going back. That told me how it all works
Interviewer	Did you find any problems with the analogy?
Student 013	No
Interviewer	Did you use the analogy to help you answer the question about the ammeters or did you just know it?
Student 013	I used it, yes I used it
Interviewer	How did you use it? When you looked at

	it can you go back through your thinking, which is what I would like you to do.
Student 013	I just thought of it as the classroom yes and this was everyone was giving out paper
Interviewer	But did you do this, you were very quick at coming up with an answer, you didn’t sit there and look at it. Did you think of it as people or just “I know what the answer is”?
Student 013	I thought of it for about a second and then remembered
Interviewer	Are you aware of any ‘tricks’ or ways that you use to remember things , concepts. How do you remember
Student 013	I …pause…
Interviewer	So if you have to learn something how do you do it?
Student 013	I try and memorize it, which doesn’t always work but, and sometimes there are ways that make it easier
Interviewer	What sort of ways would you use to make it easier?
Student 013	Um don’t know …pause… I cant think of any
Interviewer	Can you think of how you remember things in science for a test, how would you go about remembering?
Student 013	I guess if I was studying for a test I would get out my book and my sheets and make notes on the information
Interviewer	Are you aware of the sorts of things that you remember best in science?

Student 013	I remember the things that I found interesting
Interviewer	So can you give me an example?
Student 013	Yeah I found electricity interesting, um and I remember that, because it was you know
Interviewer	Anything else
Student 013	Yeah …long pause…
Interviewer	Do you want me to go back over some of the units, you've done; cells, you've done chemistry in year 8, you did ecology in Year 8, you did um
Student 013	The one in year 8 was, it might have been chemistry in year 8 and it was really interesting
Interviewer	What about this year are there any units you have found interesting this year?
Student 013	Um, the one we are doing now, that we have just started, looks interesting
Interviewer	What's that one?
Student 013	The um the plant and animal reproduction
Interviewer	So what sorts of things do you remember best, you're saying things that are relevant and interesting But do you remember lots of little detail or remember big pictures?
Student 013	Um I can some units I remember little detail some units I remember big pictures
Interviewer	So what is a unit you would remember little detail?
Student 013	Um from in yeah in bits of detail um the unit in year 7 where we made oxygen and carbon dioxide and what was that?

Interviewer	That was in the introductory unit where we made gases and then tested them, That was fun!
Rbert	Yeah, I remember little details from that how things are, how some gases are heavier
Interviewer	So what does this say about the way you learn?
Student 013	Pause…
Interviewer	What do you think would make it easier for you to learn?
Student 013	Um it would make it easier if I don’t know… pause …If I could like, you said something earlier about learning tricks that would help I think if that sort of thing goes with something to remember it would be easier I guess I am also thinking about this sort of stuff where we did a role play and gave you away that you could remember the ammeters stay on, or they are both the same.
Interviewer	Do you use that sort of stuff?
Student 013	Yes
Interviewer	But you don’t make them up for yourself? Do you remember reading them in any of your textbooks?
Student 013	I don’t
Interviewer	Thank you very much

Interview

Student 014

Date: 11 October 1999

Interviewer	So this is an electric circuit, it’s got a battery in it here a bulb and it’s got two ammeters. At this stage it is open, but assuming that you close the switch can you tell me what you think the reading on the two ammeters would be?
Student 014	Um they’d be the same
Interviewer	What I am looking for is how you really think. So you think they’re the same
Student 014	Yes, I suppose so
Interviewer	Can you tell me how you came to that result, what sort of thinking you did that got there?
Student 014	Just that an ammeter measures current, and current is the same throughout even when it goes through a light globe , it just remains the same
Interviewer	In Year 7 we developed an analogy for electricity where we used a coal train and we also used a role-play where we stood around the room with bits of paper. Can you remember that? Can you describe it to me?
Student 014	Its when everyone has a piece of paper and its like the current and as you go around as you pass through the light globe its like more friction and all that as you pass through and the pieces of paper get handed on and the current continues around. I don’t know if the pieces of paper really go back to the battery
Interviewer	So what happens to the pieces of paper?
Student 014	They get given out. They give it to the light globe there, then they go back to the battery to get pieces of

	paper again and go around
Interviewer	So what goes back to the battery?
Student 014	Oh the people like they're simulating the current
Interviewer	Can you remember whether this analogy helped to explain how electricity worked?
Student 014	Ah Yeah, I think it did. Cause it was pretty hard to understand electricity at that stage yeah but that..
Interviewer	Can you think how this helped?
Student 014	Probably just to show the difference between like current and that and like how the voltage and something and how it's not the actual current that gives like the light
Interviewer	Did you find any problems with the analogy? And did we have to change it at all? Or did you have to change it in your head to be able to use it?
Student 014	Pause I'm not too sure I don't think I changed it that much
Interviewer	Did you use the analogy to help you answer the question about the ammeters today?
Student 014	Ah yes sort of yeah cause the analogy that had the current remains the same throughout its just the pieces of paper their the only thing that changes
Interviewer	Or did you use the analogy or did you just look at that and know what the answer would be?
Student 014	Oh well I don't really remember the analogy I just answered the question
Interviewer	So when you looked at that how did you work out that it was the current that didn't change in the ammeters, what sort of thinking did you use?
Student 014	I sort of remembered from Year 7 that the current never changes, its always the same although I may have had that at the back of my mind, from that analogy bit I'm not too sure its just that knowledge

Interviewer	Do you use any special things to help you remember ideas and or concepts in science?
Student 014	Pause Sort of , it depends on what it is for the things that are harder to understand I would
Interviewer	Can you give me an example
Student 014	Pause Like waves and that I think of it as water waves as against light in refraction and that when it gets shallower and changes speed changes direction and that I think of it as that cause I try to make it a bit easier
Interviewer	Are you aware of the sorts of things that you remember best in science?
Student 014	How do you mean?
Interviewer	Are there some things that are easier to remember in science than others?
Student 014	Well, I think that , if you mean topics
Interviewer	Yes and no. some people remember biological things some people will remember this sort of diagram easily, some people like lots of detail, some people like big pictures
Student 014	Oh just from sight
Interviewer	Ill rephrase the question. Can you remember a lesson that stood out in science that you have had?
Student 014	Yes , just this year
Interviewer	And what was it on?
Student 014	Geology and that
Interviewer	Okay so what did you do, what happened in the class that made it memorable?
Student 014	It was just explaining how dykes and sill and plutons and batholiths under the ground and how its always changing, erosion and all that
Interviewer	So what made that interesting for you?
Student 014	It had a big diagram and I could see like it changing.

	He'd rub it out and then draw the next stage and that and so on and you could just see the process and steps and how it happened
Interviewer	What do you think that says about you and the way you learn things
Student 014	If you could actually visualize it, visualize it happening it makes it a lot easier ..In Biology you can actually visualize things happening but it makes it a lot harder in things like chemistry and electricity where you don't actually visualize the current and that but if you have analogies and that and diagrams it sort of helps out a bit
Interviewer	So do you make up any for yourself?
Student 014	Oh I did for that light refraction with water waves, not very often but if something comes to mind as soon as I think of it I think of that
Interviewer	So do you use the analogy now or have you moved on beyond the analogy, for the light waves?
Student 014	Yeah I sort that helped me at the start that analogy but now I'm sort of grasped the concept so I don't use the analogy that much
Interviewer	Thank you Student 014

Interview

Student 015

Date: 11 October 1999

Interviewer: Here you have the circuit, which you have seen before in previous years, it is an open circuit. If we close the circuit can you compare the reading on the two ammeters

Student 015: You want me to tell you what then

Interviewer: OK lets change this, lets make this ammeter 1 and this ammeter 2, so can you compare the reading on those two ammeters?

Student 015: They would be the same except, is the electricity going round this way

Interviewer: It doesn't matter which way the electricity is going

Student 015: OK well if it is going this way If it is closed, it will be almost the same reading, but yeah it will be the same reading

Interviewer: Are you sure?

Student 015: Yeah

Interviewer: Explain it? Can you explain why?

Student 015: Because, OK this is what I remember, we were trying to figure out, it cant be the same actually, because how does the battery lose electricity, so actually, maybe it is a bit lesson this one each time on this one it reduces the reading mmmm That is all I can say. This is a globe?

Interviewer: This is your battery, this is your globe, and these are your two ammeters there

Student 015: OK

Interviewer: In Year 7, remember we developed an analogy, we used coal train and we also had people standing around the room with bits of paper. Remember that?

Student 015: Yeah

Interviewer: Can you explain it to me

Student 015: We were just, is that the one where we were trying to act out as electrons?

Interviewer : Yes

Student 015: And basically we were showing that they are all already there, they are all there, and so we don't make electrons we are just stimulating them, so they are all already there and electricity just passes through them. That right?

Interviewer: There isn't a right. Did this analogy help you to explain how electricity works? I am thinking back then.

Student 015: Um yeah I think so. I think it. Yeah it was because then it gives you something. I remember in Year 7 I told myself when I was studying I was thinking of electrons as little people, so yes I guess it did.

I: Did you think there were any problems with the analogy? Of using little people as electrons?

Student 015: Well I mean it wasted time getting people in line, I mean it is a bit distracting. I remember it wasn't all that clear at the time you have to think about it as well. It doesn't just when you get in the line you don't understand it straight away but I mean it helps. I think it helps in different ways cause then you realize what exactly is meant when you move but problems? What do you mean by problems?

Interviewer: Did you have to change it, did you have to alter it? You have introduced the thing about it being time consuming to construct it

Student 015: I mean you could just say there's lots of little electrons and they are all around the circuit, maybe some people its useful to get in a circle, I mean if I was just told that that’s what there was I could just imagine it

Interviewer: Did you use the analogy to help you answer the question about the ammeters today?

Student 015: Umm (12 seconds) I guess the way I think about electrons never changes.

I: OK So once you’ve made the fact that there are lots of little electrons going through you didn’t have to think of them as people any more?

Student 015: Well I don’t have to but yeah I guess I used it in one sense but I didn’t think of it as people any more but I mean the analogy helped me to get, you know. It wasn’t a conscious thing but subconscious. It helped. I wasn’t thinking of people standing around.

Interviewer: That is what I wanted to know

Student 015: I just translated it back

Interviewer: Are you aware of any, I've used the word “tricks” or ways that you use to help you to remember concepts in science

Student 015: Mmm I think the people one is good, with the electrons being people, that’s one example of what you are saying

Interviewer: What I am asking is when you sit down to learn are there any ways

Student 015: Yeah, yeah, yeah use the word. If there is a sequence or a list, you know, try and make a word, lets say I have to remember Principal, Deputy Principal, Arts, I remember um something starting with PRAD, what else, pictures, like.

Interviewer: Can you explain where you have used pictures

Student 015: Like in biology, and rocks and stuff, instead of just remembering how to do it you remember the picture and you just, the information You know it would be like how the text book has a picture showing you what it is talking about, if you remember the picture it is easy to remember, because it makes sense you know.

It’s a visual queue

It's not words you can see it. So for tests and stuff I try to remember the picture more than I actually memorize the paper. Last test we had to find the epicenter I remember I don’t tell myself first you find the measurement of this, and this and this. I just remember it looks like that and I know how to do it

Interviewer: OK

Student 015: I just remember what it looks like and its just logical

Interviewer: So what picture have you got in your mind. I've got a picture in my head of how I would find the epicenter, what sort of picture have you got in your head

Student 015: Of epicenter

Interviewer: Yes

Student 015: OK Well, you use the radius from three different points and it comes to one point. Cause we did that in class, and because I remember the sheet where we were drawing it so if I am given measurements I understand what I am meant to do. And for a really obvious one is the rock layers like I just remember if it's like this, or like this it’s a fault, if its like this its erosion and whatever, instead of remembering. If it's curvy then its erosion. I remember the curves.

Interviewer: Are you aware of the sorts of things, which you remember best in science?

Student 015: Yeah, the things that uh, the things that hit me that I think I will remember forever are, even though I got very confused in this electricity unit in year 7 it helped me in a lot of ways to understand how things work, like a fuse. Ill never forget thinking Oh so that’s why those lights go out. When it happens so now you know. It's like some things you never forget. Biology, you know it's hard to forget, if you have a cut you see the cells. The things that you see happening you remember , things that are really amazing like in physics inertia and stuff, things that you see happening you relate it back to what you learnt in science

Interviewer: Inertia is going back, you are talking about what we did in year 7 and a lot of that stuff has stuck, hasn’t it

Student 015: Yes the stuff that really hit you, or hits me, those things I remember.

Interviewer: So what sorts of things don’t you remember?

Student 015: The real issue is that a lot of the things are interesting but when you worry about the test, you end up just learning it for the test, That’s what I do, I still do it. When you do that, you forget it so there are some things like the tests… okay, the tests for copper sulfate crystals and all that kind of stuff I don’t remember any experiments. I don’t remember any experiments at all because I don’t see it. I don’t see it day to day so the reason I learn it is for the test I don’t learn it for any other reason and if anyone says copper sulfate I remember copper sulfate but I don’t remember the test I don’t remember what we actually do with it. The things with cells and electricity and inertia I remember, you know what I mean. There are some bits you just remember; you don’t see any other reason for knowing it. That’s just science is everything, so some bits you see often some bits you are not really exposed to that much, those are the things I just don’t remember. I think that’s a reason why a lot of people don’t enjoy different parts of education cause people say if I don’t have a use for it so why should I have to learn it so I don’t care about it. Know what I mean?

Interviewer: It’s the relevance

Student 015: Yes, it’s the relevance. But everything is relevant in some way. Someone has to learn about physics, otherwise we don’t know anything

Interviewer: But this is all Physics

Student 015: But I mean Chemistry, this year we did a bit of chemistry and I remember the whole time half the class that is not good at it is not sinking in, they don’t understand, they’re telling themselves “I’m never going to use this, I’m never going to use this, I don’t care. That stuff we’re not going to remember again next year, you know what I mean? The stuff about the urinary system, which we all went “Oh wow, so that’s what is happening “; everyone is going to forever.

Interviewer: What do you think this says about your learning?

Student 015: Ah…I guess Mmm, I guess it says that. I’m not saying that I don’t try even if I’m not interested, I still learn it but its not just something I learn to keep, I learn it so I can do okay.

Interviewer: So do you learn in big pictures or do you learn lots of little detail?

Student 015: For the test I learn lots of little detail but for the future I learn big pictures. I’ll learn the main things down the line, the detail I’ll only know for the unit really. Some things I just remember during the unit and then I completely forget about it. This is the way I am. I know some people who when it comes to the yearly they remember the details and I don't I always have to go back and learn all the details.

…After some other discussion I turned the tape back on

Interviewer: There was a lot of conflict in the class.

Student 015: I know we were trying to figure out and what is energy, how can you define energy. I remember that. Because it is a bit airy-fairy, energy is a bit airy-fairy, it's the momentum or whatever it's the going along, but its not actually the electron. The electron's not moving its just passing the energy along.

Interviewer: Do you remember that we moved?

Student 015: Oh we did move okay, that's right, well there not the ones that… Oh that's right, they've all got it but there's like, it needs to be activated so that's' when we turned on the electricity and then it moves, so we passed the energy along, the electrons pass the energy along.

Interviewer: Remember ,one person was the battery and one person was the bulb

Student 015: Okay

Interviewer: And we were all around the room, and the battery gave the person the piece of paper

Student 015: And that was energy? And the electrons were just there? Electrons bunch up don't they?

Interviewer: No they just give their energy to the bulb and the bulb lights up

Student 015: But how does the bulb light again

Interviewer: I guess they do bunch up, it becomes more difficult for the electrons to hang onto their energy while they are going through the bulb

Student 015: I remember, they did bunch up didn't they?

Interviewer: Yes but the same amount that go in come out, but it is more difficult for them to do it

Student 015: Yeah

Interviewer: I think its interesting it's like I think Ben said its not something that you can do You have to stop and think about what we were doing and there was an awful lot

231	of discussion
232	Student 015: I am sure I did not get it in class, I am
233	sure I got it afterwards. I am sure I thought about it
234	afterwards. Like when we were actually doing it -, I am sure
235	I was off somewhere and then, usually when I learn science
236	everything falls into place before the unit test, before that
237	everything is a bit up in the air, and then it all sorts out and
238	everything makes sense
239	Interviewer: So why do you think everything falls into
240	place?
241	Student 015: I'm not sure, maybe it's an effort thing, and I don't try as hard till I have to. That's part of it, I think another part especially with something like electricity after you have explained lots of different aspects to it the whole, the simple bits make more sense as they've got more backing to them

Interview

Student 018

Date: 11 October 1999

Line number	Transcribed interview	
001	Interviewer	This goes back to that electricity unit we were
00		dealing with. This is an open circuit. This is your
002		battery, this is your bulb and you have two
003		ammeters. If you close that circuit, can you
004		compare the reading on the two ammeters?
005	Student 018	Um I think they are the same
006	Interviewer	Can you explain it?
007		Can you explain why you got that result?
008	Student 018	Does ammeter measure voltage?
009	Interviewer	No ammeters measure the current.
010	Student 018	Which way is the electricity going?
011	Interviewer	The current is going this way
012	Student 018	Okay then ammeter 1 has more current than
013	ammeter two	

Interviewer	How did you get that result?
Student 018	Cause the current decreases after the light bulb
Interviewer	In Year 7 we developed an analogy of electricity, which used a coal train, do you remember that?
Student 018	Not the coal train
Interviewer	We also did another one where we did a role play where we stood up around the room and had bits of paper, can you remember that and what we did and can you explain that to me?
Student 018	We all had a bit of paper and we walked around where there were two people being the light bulb and we all walked into, or between the two people and put the paper down and there was bunching before the light bulb because we had to wait to put the paper down and then there was friction there so it creates light then you go around again to get the paper from the battery again
Interviewer	Did that analogy help you to explain how electricity works
Student 018	Yeah
Interviewer	Can you explain how it helped you? To actually do it you get a better idea than just listening to words Do you think there are any problems with it?
Student 018	That role-play?
Interviewer	Yes
Student 018	Not really
Interviewer	Did you use the analogy to help you answer the question about ammeters today?
Student 018	Not really
Interviewer	Okay that’s fine. Are you aware of any “tricks” that help you remember things in science? I mean “tricks” being any way that you help to remember

	things.
Student 018	For the electricity?
Interviewer	No anything
Student 018	No
Interviewer	No. Have you ever thought about how you remember things?
Student 018	Not yet. Before any exam?
Interviewer	Okay, so what do you do before an exam to remember things?
Student 018	Just read the textbook and write some recorded notes and look through your work
Interviewer	Okay, so you are just making notes, that's what you do when you remember
Student 018	Sometimes if there are pictures they are easier to remember than the words
Interviewer	What sort of things do you remember best in science?
Student 018	What do you mean?
Interviewer	Are there any areas of science or any lessons that stand out as ones that helped you to remember things or you find you remember even now Like that role-play What about in chemistry is there anything that helps you to remember things in chemistry?
Student 018	Sometimes diagram, I mean experiments you can remember them, or some of them
Interviewer	Why do you think that's so?
Student 018	Because there not just remembering just words
Interviewer	So what do you think this says about the way you learn?
Student 018	Sometimes it's easier to learn when you actually try things out for yourself

Interviewer	So can you think of a example of something where you have tried something out for yourself
Student 018	Like major science assignments
Interviewer	Give me an example
Student 018	You can read in a book that something happens to a plant and when you actually try it will stay in your mind heaps longer cause you’ve done it yourself and you saw it for yourself
Interviewer	So what did you do with plants?
Student 018	I got some Elodea and put it in this beaker with water and you see it go hard as the water decreases and stuff
Interviewer	Thank you for that