Science and Mathematics Education Centre

Geological Science Education and Conceptual Change

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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Signature: G. D. Vallender

Date: 9/6/10

ABSTRACT

Geological science is a fascinating subject of learning. We live with and are surrounded by the results of complex natural phenomena such as plate tectonics, earth system interactions and natural hazards such as volcanoes, earthquakes and tsunamis. We are also one of the products of billions of years of biological evolution. These topics form an essential part of all science curricula and are a vital part of an individual's scientific literacy, yet the geological sciences struggle for existence in most secondary schools, many tertiary institutions and especially teacher training establishments. A selective overview of the international geological and geoscience curricula is presented. This thesis investigates key issues associated with the teaching and learning of geological science: curriculum and assessment issues, conceptualisations of geological time, biological evolution (within a geological context) and visual spatialisation aspects such as visual penetration ability. Geological science is discussed and differentiated from the generalised label of earth or geoscience and the environmentally oriented Earth Systems Science.

The theoretical framework is grounded in constructivist principles and conceptual change theory. Conceptual change in this thesis is viewed as an evolutionary and ecological mechanism of learning within a multidimensional and individually intentional world view. The conceptual status of geological science is investigated from a wide age range of respondents from three different cultural settings: Lebanon, Israel and New Zealand. Data gathering used a modification of pre-validated questionnaires, unstructured respondent interviewing and selective analysis of secondary data. Internal triangulation enhanced reliability issues generated by questionnaire methodology. A case study approach was utilised for discussion of geological science curriculum issues.

The history of geological science, conceptualising geological time and student understandings of the fossil record are placed within a conceptual change context. Here, conceptual change theory itself is evolutionary in nature and fits well with an analogous concept of punctuationism. In short, the rise of conceptual change theory from a 'Piagetian' stasis over the last 30 years has shown a rapid diversification of

approach and ‘niche’ since the mid 1980’s. New Zealand is used as a case study for the status of geological science in a national secondary school Science curriculum.

Through stratigraphy, the fossil record and rock deformation, geological science uniquely involves ‘Deep Time’. The GeoTSAT questionnaire instrument asks questions about conceptualisation of relative geological time as deduced from correlation of stratigraphic columns and Steno’s laws of superposition. In essence all age groups from age 13 to 40 years are cognitively able to correlate strata but all groups also demonstrate the same kinds of misconceptions and difficulties. Aspects of diachronic thinking are applied to the interpretation of responses to the GeoTSAT questionnaire. Developing manageable teaching techniques in teacher training institutions that are relevant to the geological sciences for conceptualising scalar dimensions of time, mass and distance are important challenges for educators.

Visual spatialisation of deformed rock strata is a key skill in interpreting a geological history. The GeoTSAT questionnaire asks respondents to complete block diagrams of simple geological structures. All age groups again have the same kinds of difficulties in mental rotation and other spatialisation skills such as visual penetration ability. Visual penetration ability is further investigated with the use of a ‘hands on 3-D model.

The GeoVAT instrument asks questions about the nature of fossils, the relative timing of geological and fossil events in Earths history and the links of fossil organisms with their life environments. The challenge for educators is to find ways of pedagogically strengthening the contextual links of learning about extant life with extinct life and the importance of the fossil record in the training of biology teachers. Improving the connections between the geological sciences, biology and environments is a key challenge for educators. The thesis concludes with a summary of findings, limitations and future directions for teaching and learning geological science in school curricula.

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This thesis would not have happened without the love and encouragement of my parents who instilled a love of learning and a desire to understand the world. Dad, who was a philosopher, great listener, practical man and encourager who had not only the ability and vision to provide opportunities, but also allowed his two children to follow their own paths. Mum was always there with that quiet loving support that is too easily taken for granted. Thank you Mum. Leaving your families to live in a far away country so that your children could have a better opportunity in life was a worthwhile and courageous sacrifice. Thank you both and I love you heaps. And Dad, I hope you have now found your very own universal space/time string.

To Elaine, thank you for putting up with years of my ‘oddball’ study that must seem to have gone on forever and ever, and for making me think about how others might read and understand this stuff when I probably should have been digging the garden or painting the roof or doing something else. This thesis is also for you. I love you for you being you and your enormous gift for giving your talents to the world through music and Girl Guides. My life with you has been enriched beyond words.

To Professor David Treagust at SMEC, thank you for sharing your wisdom and allowing me to ramble on and guiding me to find direction in a conceptual swimming pool throughout this journey. This thesis would not have got there without you and I hope that the conceptual vitality of the geological sciences becomes a more important place in the teaching of teachers and that more research is conducted into this exciting and relatively untouched field.

To my colleagues and friends over the last 37 years and especially questionnaire co-ordinators, your comments and discussions about science teaching and learning have often, more than you think, redirected and shaken my thinking: thank you.

Lastly, I would like to thank those students and teachers who have contributed their thinking in supplying the data. In amongst the ‘saboteurs’ there is revealed a conceptual flower bed which helps provide a small window into how we all think about essential concepts of geological science and how we can teach and learn better.

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CHAPTER ONE

GEOLOGICAL SCIENCE EDUCATION

1.1 Introduction

As a rarish geology/biology graduate teaching secondary school science and biology, in New Zealand, I have long been interested in the status of the earth sciences in school curricula, tertiary institutions and secondary teacher training. An interest in geomorphology at the age of 15, sparked by Harold Venz, a geography teacher, led to the eventual discovery of a subject called geology and a realisation that hills were not just hills; they weren't just surface features but had depth and told a deeper, longer and more interesting story than the 'Wars of the Roses' and 'Othello'. I always wondered why schools never taught geological science but left it to be accidentally discovered for those bound for university study.

In New Zealand, lecturers at university are not, as a rule, specifically trained in the pedagogy of their specialist subject. Consequently, the development and position of the teaching and learning of the earth sciences in many countries of the world is a major concern to the international geological community as well as at a national level. In Britain for example the introduction of the national Science curriculum in 1989 contained an earth science component that was new (King, 2001; Oversby, 1996) but one poorly integrated and implemented. In New Zealand also, the 1994 introduction of earth science and astronomy as *Planet Earth and Beyond* into the national science curriculum was heralded with earth science being accorded equal recognition with physics, chemistry and biology at the senior high school level (age fifteen to eighteen years) where high stakes national qualifications dominate the curriculum. This development occurred after no serious recognition in all previous national curricula except physical geography courses. In today's world especially, an educated population significantly benefits from a knowledge and understanding about earth resources, materials, geological processes, history, natural hazards and evolution (Turner, 1996). The US National Science Teachers' Association and the American Geological Institute (2004) clearly outlines the unique values that the earth sciences bring to student's and populations' developing scientific literacy. Geological science is the glue that holds the geosciences together.

Of complementary importance, educators also need to be better informed on how and why students conceptualise specific aspects of earth science so that teaching and learning can be enhanced and further developed. Results in the New Zealand experience of a new National Certificate of Educational Achievement (NCEA) (www. nzqa.govt.nz), assessment system suggests that there is a desperate need to understand how and what earth and geological sciences are being taught and how students and teachers conceptualise key **geological** ideas.

This thesis focuses on specific aspects of conceptual change within a manageable international framework and attempts to investigate key concepts that help define the earth sciences as a unique discipline of learning: biological evolution, geospatialisation and geological time and history. Chapter 9 specifically describes a case study of the status of geological science in a national Science curriculum.

1.2 Geological Time

Earth science is an historical science discipline that interprets the evidence provided by the natural laboratory of the Earth to give a scientific understanding of its history and processes. Geological history cannot be interpreted successfully without reference to relative time and absolute (radiometric) time. Understanding geological time and its place in this interpretation is a unique and fundamental characteristic of the discipline. Conceptual development of time relationships is linked with an essentially Piagetian view of cognitive development and spatial visualisation of 3-D structures, crosscutting relationships and geological event time sequencing. The ability to spatially visualise geological structures is a fundamental activity to be mastered for progress in the geological sciences. Together with an understanding of students' knowledge and how it develops (constructivism and conceptual change), understanding the teaching and learning of these skills forms a key aspect of this thesis. Indeed, Mathewson (1999) points out the importance of visual–spatial thinking for scientific creativity. Similarly, Orion, Ben-Chaim and Kali (1997) showed that interviewed students claimed that only their earth science courses required development of spatial-visual thinking skills. Kali and Orion, in their paper on spatial abilities of high school students in a geological context (1996), suggest that further research on the visual penetration abilities of students would be fruitful. This aspect is addressed in the geological time and spatial ability test instrument (GeoTSAT).

Again, recent key work by Dodick and Orion (2001) and Trend (2000) have begun investigations into conceptions (and perceptions) of geologic time with various groups. This thesis builds on previous work across a wide age range and across different cultures and curricula.

Dodick and Orion in particular build on the work of Ault (1981; 1982) and Montangero's (1996) diachronic time concepts in developing instruments (GeoTSAT) for investigating geological time conceptions. This research helps answer for example, the question -'at what cognitive, curricular and cultural point do students visually and spatially penetrate a geological structure'? This research intends to develop further these instruments and apply them to measure conceptual change in an international framework.

1.3 Evolution

Like the biological sciences, nothing in the earth sciences makes sense except in the light of physical, chemical and biological evolution (Dobzhansky, 1973). Along with the conceptual development of 'Deep Time', evolution and the fossil record are unique and important characteristics of the earth sciences. Evolution of living organisms as seen through their fossil remains is intimately related to this sense of 'Deep Time' and modern biological principles are used as a key for unravelling the past history of life.

Understanding evolutionary principles is a unifying theme and understanding geological history is dependent on an understanding of the fossil record. Because geologists have been more directly involved in 'digging up' the past, the fossil record has been studied more often within a geological framework such as for strata correlational history rather than a biological one. But of course there is more to paleontology than this. Perhaps this helps explain why there has been little connection between biology and paleontology and confusion when curricula are developed for ‘evolution’ sections in the biological sciences in high schools. Indeed, Woods and Scharmann (2001b) readily point out “if we are, as a science education community, to do justice with respect to evolutionary theory, how might we more effectively integrate evolutionary theory within the biology curriculum?” (p.1). In New Zealand, for example, the Year 12 national biology curriculum has recently removed from assessment, the evidence for evolution and there is no mention of paleontology per se in any curriculum: although implied, it is not adequately integrated with the teaching of biology and geoscience.

This thesis will investigate how students conceptualise fossils and the fossil record, its place as a scientific unifying theory and how earth scientists use it to construct an understanding of Earth history.

1.4 Conceptual Change

Underpinning this project is the notion of conceptual change (Bezzi, 1996b) where according to Tyson, Venville, Harrison and Treagust (1996) conceptual change is considered to be the building of knowledge (constructivism) through actively generating and testing ideas. Macbeth (2000) described conceptual change as being about how students’ understandings of the natural world changes from what they bring with them into the classroom (world view) compared to what they take away with them. There is a vast literature base on conceptual change (Duschl & Gitomer, 1991; Hashweh, 1986; Kuhn, 1962; (Posner, 1982; Strike, 1992; Tyson, 1997; Vosniadou, 1994, 2003) which describes a picture of how conceptual change theory itself is evolving (See Chapter 4) and becoming vastly more complex and multidirectional (Ohlsson, 2009; Treagust & Duit, 2008; Vosniadou, 2007a; Vosniadou, 2007b; Vosniadou, 2009). Ohlsson’s resubsumption is a very long way from Posner et al.’s ‘weak accommodation’!

Just how and when do students develop their concepts of geological time (deep time) and evolution, and within different curricular and cultural settings? Conceptual development and understanding of the fossil record is fundamental to the biological and earth sciences and is the cornerstone of evolutionary theory. A study by Desmastes, Settlage and Good (1995) investigating patterns of students' conceptual restructuring within the theoretical framework of biological evolution used conceptual change theory to define some limits of the theory and suggest other models of restructuring. This study has some implications for this research. Cobern's (1994) conceptions of worldviews of student's on the teaching of evolution have been roundly 'counter pointed' by Smith's (1994) argument on the teaching of evolution. By understanding how conceptions (and misconceptions) develop and maintained, there is a better chance of improving teaching techniques and enhancing student understanding of evolutionary principles and geological time and spatial visualisation within an earth science context. The notion of persuasion (Woods, 2001a) as a metaphor for conceptual change processes is examined by investigating aspects of curriculum design and 'what teachers do'. This thesis investigates how this knowledge construction occurs in an earth science context.

1.5 Significance

Geoscience education research is a late developer and as geological and environmental change becomes more obvious, it exposes how under taught and understood this subject is at the primary and secondary levels around the world. The development of computer modelling of 3-D geological structures is a good example of how relatively new teaching methods have built on an understanding of student conceptualisation and spatial visualisation of geological structures (Kali, 2003) (See Chapter 7). Better understanding of 'where students are at' in terms of their conceptualisation abilities has implications for teaching techniques and curriculum development. It means that courses can be structured to meet student (and teacher trainee) cognitive needs rather than perpetuate current models of teaching the broader earth sciences and geological science. Educational research within the earth sciences is not vast, but because we depend so much on the Earth for our well being the earth sciences have been gaining ground as a subject and discipline of learning through linkage with environmentalism and Earth System Science (Mayer, 1999). This thesis is designed to add to our understanding of how students conceptualise fundamental aspects of earth science and how curriculum development, and teacher training can be enhanced. Researchers will benefit by an understanding of earth science conceptualisation from within an international framework. Both areas of study (paleontology and geologic time) are unique to the earth sciences and, as Orion and Kali (2005) have shown, there are many future directions and spin-offs that can happen. For example, the developments of new learning tools and better targeted syllabi and curricula have the potential for globally improving geological science education.

1.6 Purpose of the Research

The purpose of this research is to investigate, define and evaluate developmental changes in conceptualisation of two key aspects of student understandings within the earth sciences. These two aspects involve conceptualisation of biological evolution, as embedded in the sub-disciplines of paleontology and paleoenvironment, and conceptualisation of geological time itself as related to geological structures, correlation, and sequencing, and of course the fossil record as related to evolution. These concepts are the fundamental cornerstones of any understanding of earth science contexts. An important objective of this research is to investigate conceptualisation (and conceptual change) of biological evolution and geological time across international (cross-cultural) boundaries, wide age ranges and within different curricula. It is an attempt to look at the conceptual status of students at various ages and within different cultures and science curricula. In particular, this research specifically addresses questions related to conceptions which students' hold for key aspects of earth science education: time, structure and fossils.

1.7 Research Problems

Cognitive development and understanding of geological processes and histories is dependent on the development of workable (understandable) conceptions of processes, time and space. As a historical science, earth science or geoscience demands an understanding and conceptualisation of the immensity of geological time

(Deep-Time) and its relativities, and an understanding of the evolution of life within this time framework. How individuals develop their conceptions of biological evolution and geological time within different cultural and curricular frameworks forms the basis of this research project.

A challenge for educators of earth science at all levels is to develop more efficient and relevant ways of teaching these concepts and move students forward to a more useful and sophisticated understanding and conceptualisation of how the Earth works, what it is made of and its history. Indeed, there has been a strong call in the past decade from the international earth science community (e.g. (Akhatar, 1996; Cooray, 1996; Mayer, 1997; Stow, 1996) to improve and enhance the role that this discipline can play within science curricula. Data on geoscience curricula (Clark, 2006; King, 2003, 2007) has been gathered from Europe, South Africa, North America, South America, Eastern, Southern and Western Asia, and Australasia, indicating that the call has been slowly answered (See chapter 2). A deeper understanding of student conceptual development of evolution and geological time through a range of ages and within different cultural and curricular frameworks may provide insights into developing further earth science education and teacher training education within a constructivist framework.

1.8 Research Questions

The fundamental question being addressed in this project relates to how students within a wide range of ages and within different cultural and curricular settings develop and change their conceptions of geological time, biological evolution and the fossil record. Conceptual change within different settings forms a focus for this research and attempts to address perceived teaching and learning issues for earth science education, primarily in schools but also in teacher education institutes and universities.

Research Question 1

What are the characteristics of international Geoscience curricula and their implementation, with particular case study reference to the New Zealand curriculum?

Research Question 2

How do students aged between 12 and 40 years develop their conceptions of evolution and the fossil record, geological time and 3-D geological structures?

Research Question 3

What is the influence of diachronic thinking on conceptions of geological time, structures and fossils?

Research Question 4

What is the influence of visual/spatialisation on conceptions of geological structures?

Research Question 5

How do conceptualisations of fossils, geological time and geological structures vary with age of respondent?

1.9 Towards Defining Geological Science

> *"Understanding is always a journey never a destination"*
>
> (Fortey, 2005, p.25).

It is not surprising that different conceptual understandings of what is actually meant by Geoscience exist: they represent the evolutionary growth of knowledge and contexts. Indeed, these different conceptualisations and understandings of what might constitute Geological Science is a common cause of confusion and has important influences on curriculum design, content delivery and assessment. The title 'Geoscience' has different 'global' meanings relative to Science/Geography/ Environmental/Earth Systems curricula but has a history in western culture very much controlled by British eighteenth century colonialist thinking. Geology as a descriptive name is a term no longer easily understood by many people including educators, and, more often than not has the connotation of being just about "boring old rocks and fossils". Rarely is geology seen as a vital historical science that investigates the physics and chemistry of 'beneath our feet' and the history of this planet and its life.

Although some recent local attempts such as the ANSTO (Australian Nuclear Science and Technology Organisation) initiative in Australia has improved science enrolments in New South Wales by encouraging a careers-based core (Australian Government, 2007), locally (and globally) the study of 'Science' in schools has been in decline since the late 1960's (Venville, 2008). The Geosciences are particularly vulnerable due largely to lack of resourcing, incompetent teachers and teacher training, and perceptions of value. The term Geoscience, containing the word 'Science', may also carry negative perceptions for many educators and students. Geography is in many schools largely a social science and looks at people distributions and interactions in connection with natural landscapes. Issues surrounding 'branding' and naming do not escape subjects of learning. It is likely that the nature of Geoscience (not geological science) will continue to broaden and be more multidisciplinary rather than deepen and narrow in a response to global environmental change and educational trends. In schools, an effect of this is shown by an increased connection of Science with social science by attempting to show how Science is relevant to people.

For the purposes of this thesis, Earth Science (ES), Geoscience (GS), Geology (GL) and Earth Systems Science (ESS) are not considered synonymous but the core *Gê* - the Earth, is. The key features of these descriptive titles is summarised in Table 1.1. Despite the neptunist/vulcanist controversy, geology was first taught as a fledgling stand-alone subject (rather than as part of 'natural history philosophy') by Abraham Werner around 1775 at the Mining Academy in Freiberg in Germany (Ireton, 2003). Although a mineralogist Werner taught stratigraphy, but in the process, erroneously taught that earth materials all precipitated from sea water thus beginning the debate about the origin of basalt and other igneous rocks. The essential elements of commonly interrelated titles used to describe the Earth and geological sciences are shown in Table 1.1. The intent is to establish that although the various 'species' of geoscience are closely related they have different purposes and meaning in different curricula. For example, describing and explaining the physics of seismic waves is not the same as describing and explaining the effect of seismic waves on people and property.

Table 1.1 Definitions summary of Geological Science and Geoscience.

Title	Description
Earth Science (ES) and Geoscience (GS)	Synonymous with Earth Science, Geoscience focuses on the teaching and constructivist learning of the solid and fluid components of planet earth and its place in the solar system **and** combined with a study of the history of life. Earth Science is much broader in approach than Geological science.
Earth Systems Science (ESS)	Focus is on the teaching and constructivist learning of **interacting systems** of the hydrosphere, biosphere, lithosphere (or geosphere) and the atmosphere. Emphasis is on the scientific investigation of processes and connections with 'Gaian' type environmentalism and natural hazards as a motivating core. Have strong links with human interactions and the environment (geography) and effects of global system interactions. It views the study of the Earth as a holistic web of interacting and interdependent cycles and chains which need to be understood in order to prevent environmental collapse.
Geological Science (GL)	Focus is on the teaching and constructivist learning of the **solid Earth** – plate tectonics, deformation and consequent structures, rock cycle, mineralogy, economic minerals, natural hazards (volcanoes, earthquakes, tsunamis, and landslides), paleontology, geological history and the physics and chemistry of the Earth's interior. It is process and composition dominated and uses multi disciplinary scientific methodology.
Geography (GG)	A traditional subject discipline often split into physical and human geography. Physical geography commonly focuses on the evolution of surface features, weather and climate, and the **impact** of natural hazards. Human geography focuses on the interaction of people with physical and political landscapes. Appears to be close to an Earth Systems approach in content by connecting social and environmental issues with surface geological processes. Physical geology is not physical geography.

As pointed out by Mayer and Armstrong (1990) (in Duschl & Smith, (2001), the traditional geological sciences of "surface mapping and mining", Earth science as a subject of learning appears to be moving towards a "causal modelling of science" for making predictions that are environmentally and socially based (Duschl & Smith, p.269). Duschl and Smith also make no mention of paleontology, tectonics, earth history, geochronology, soils, and natural hazards. Causal modelling of the earth is based on the growth of Earth Systems Science (ESS) as an innovative way of connecting students with the Earth and Science by using the Earth as the context for teaching 'Science' and global environmental problems. Certainly, remote geophysical sensing, for example, has enabled a view of the Earth's interior not possible when reliant on surface observations. Geological science is essentially the 'nuts and bolts' of the scientific gathering and testing of information (remote as well as physical), about how the earth works, what it is made of and its physical, chemical and biological history. Satellite imagery cannot extract the fossil record nor analyse the inside of granite or meteorites. It seems that Earth Science as an originally broad North American based context has evolved into a partially global ESS 'species'. Geological science (GL) is the same 'genus' but a different 'species'.

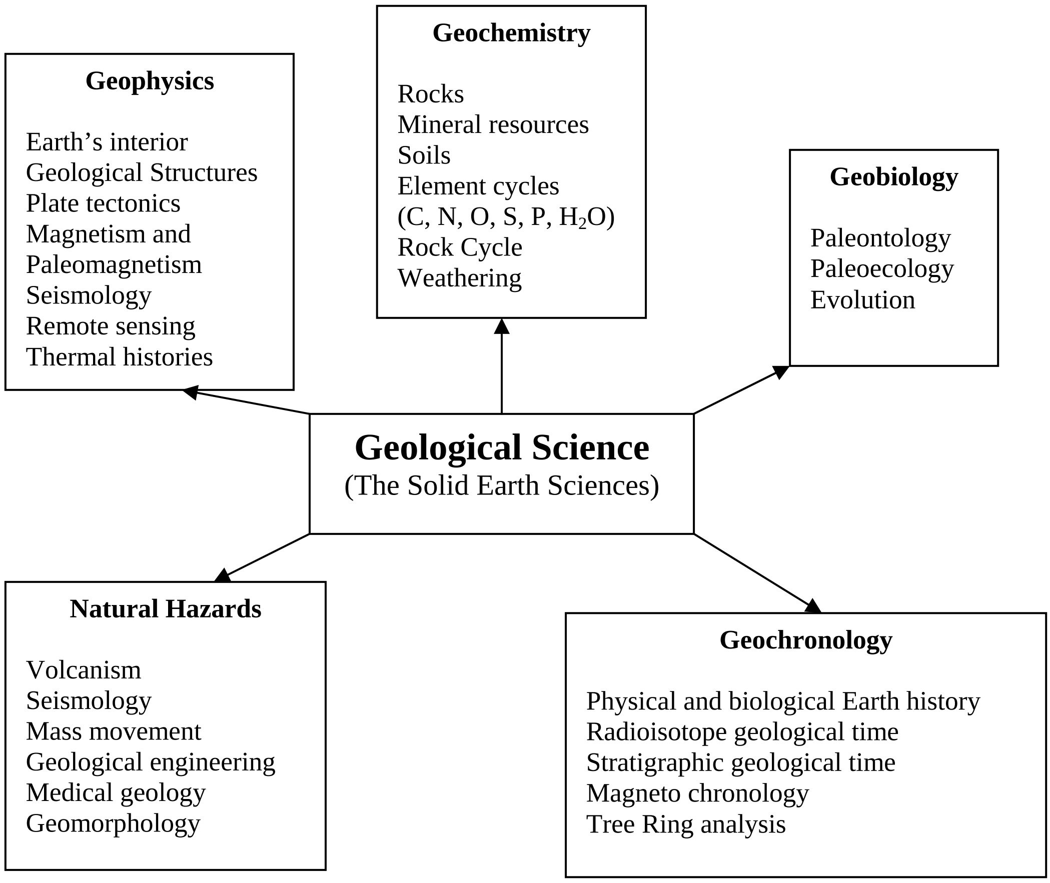


Figure 1.1. The essentials of geological science.

Because GL, ESS, ES and GS are related but not synonymous there is continual room for misunderstanding. This thesis assumes the simplified interpretation of geological science as shown in Figure 1.1 and it is beyond the scope of this chapter to argue the specific place of each sub-discipline and topic. All classification systems are a source of endless debate but inevitably diverts attention from the real issue: defining geological science is important for the development of school and university courses and curricula. Geological science (GL) then is a close relative of GS, ESS and GG but it is not the same. Three cornerstones of geological science are investigated in this thesis: evolution through the fossil record, geological time and geological structures. These three sub-disciplines are the defining issues for understanding geological history and are not addressed in depth neither by ESS nor GS. An educated population deserves the opportunity to learn about geological science but not to the exclusiveness of systems thinking and environmentalism.

1.10 Thesis Overview

This thesis addresses broad issues of conceptual change within a geological science context. The key geological issues involve geological time, geospatialisation, connections of geological science with biological evolution and curriculum delivery. Modified questionnaire instruments are used to gather information on geospatialisation abilities and student understandings of evolution and geological time. Information is gathered from a cross section of student ages and from different cultures. The following summarises the key issues discussed in each chapter.

Chapter 1 presents a rationale and background for the genesis of this thesis with research questions being posed and the significance of the work justified. It is the culmination of a life time's interest in geology and specifically geological science education: the lost and found orphan of the sciences. Because related titles described as geoscience and Earth Systems Science are commonly interchanged and rarely defined it was considered important to provide guidance on what **geological science** means in the context of this thesis. The purpose of this brief overview is to clarify and provide guidance for the structure of this thesis.

Chapter 2 provides a summary of the literature base for the two key geological science elements addressed in this thesis: geological time and geospatialisation. Geological science education research is in its infancy and this is reflected in the current rapid expansion of research into the cognitive, teaching and learning aspects of the wider issues of geoscience, Earth Systems Science and the narrower, geological science.

Chapter 3 takes a selective look at the global picture for geoscience curricula and specifically addresses aspects of research question 1: What are the characteristics of international Geoscience curricula? This chapter discusses curricula comparisons and provides some case studies. The key issues discussed address the decline and role of geological science in curricula and the place of geological science within Earth Systems Science.

Chapter 4 synthesises a general view of conceptual change theory within a geoscience and geological framework and gives details of the conceptualisation of the defining aspects of Geological science: the fossil record and evolution, geological time and spatial/visualisation of geologic structures such as faults and folds. These are key aspects of research question 2. Conceptual change issues surrounding teachers, learners and institutions are also discussed.

Chapter 5 outlines the research approach and methodology used to address the research questions. Survey questionnaires were modified and adapted from previously validated work by Kali and Orion (1996), Dodick and Orion (2003) and Trend (2001) for gathering data on conceptions of geologic time, fossils and evolution and geologic visual spatial aptitudes for geological structures. Questionnaires were prepared so that a minimum of translation of responses for non-English writers was required. This chapter also discusses issues of validity and reliability of using questionnaires and interviews. Ethical issues guiding data gathering involve a requirement for informed consent, confidentiality of responses to questions and a code of trustworthiness. Quantitative and qualitative data are used. This work is grounded within a constructivist paradigm whereby learners are assumed to evolve a personal construct of specific topics in geological science and expressed as a conceptual ecology and driven by individual intention and motivation.

Chapter 6 discusses in detail conceptual issues associated with geological time and addresses key aspects of research question 3: what is the influence of diachronic thinking on conceptions of geological time and fossils? Geological time is probably the defining concept of geological science as this contributes a unifying theme for all the other sciences. It is here that conceptual and perceptual ideas about geological time are linked with perceptions about other scalar dimensions such as mass and distance.

Chapters 7 and 8 investigate and discuss issues of visual/spatialisation reasoning within a geological structures context and specifically addresses research question 4: what is the influence of visual/spatialisation on conceptions of geological structures? Chapter 7 specifically looks at the ability of students to visually penetrate a solid object in the context of rock exposures and their underlying tectonic structures. This is further investigated with the novel use of a plasticine model outlined in Chapter 8. This also acts as a triangulation with the paper and pen exercises used in the GeoTSAT and GeoVAT questionnaires.

Chapter 9 provides for the first time, a detailed analysis of a case study describing and discussing the status of teaching and learning geological science in the New Zealand curriculum. Issues of curriculum and assessment are critically discussed. This also addresses research question 1: what are the characteristics of international Geoscience curricula and their implementation, with particular case study reference to the New Zealand curriculum? For reference Chapter 9 data are placed into Appendix 3 for reference.

Chapter 10 presents the findings and analysis of responses to questionnaires on fossils and evolution. Comparisons are made between different countries from students of similar age from 13 years to around 40 years and addresses research question 5: What is the influence of respondent age on conceptions of geological time, structure and fossils?

Chapter 11 presents the results and findings to the GeoTSAT questionnaire and also specifically addresses research question 5: what is the influence of respondent age on conceptions of geological time, structure and fossils?

Chapter 12 attempts to make some meaningful conclusions and evaluations of findings with some suggestions for further research. Connections between the conceptual statuses of student responses are discussed and linked with ideas about conceptual change in an attempt to find a way forward for geological science in school curricula and one that is aligned to the cognitive and ontological status of learners and teachers. Conceptual change is not only complexly multidimensional and difficult to attain, but to be successful also needs to be in tune with learners' conceptual status, pedagogy and a visionary curriculum. Figure 1.2 summarises the integration of research questions and methodology with the aspects of geological education addressed in this thesis. Grounded conceptual change theory permeates each issue and provides the conceptual framework for discussion. These issues involve curriculum delivery and development, student conceptualisations and perceptions of geological time, fossils, evolution and geospatialisation.

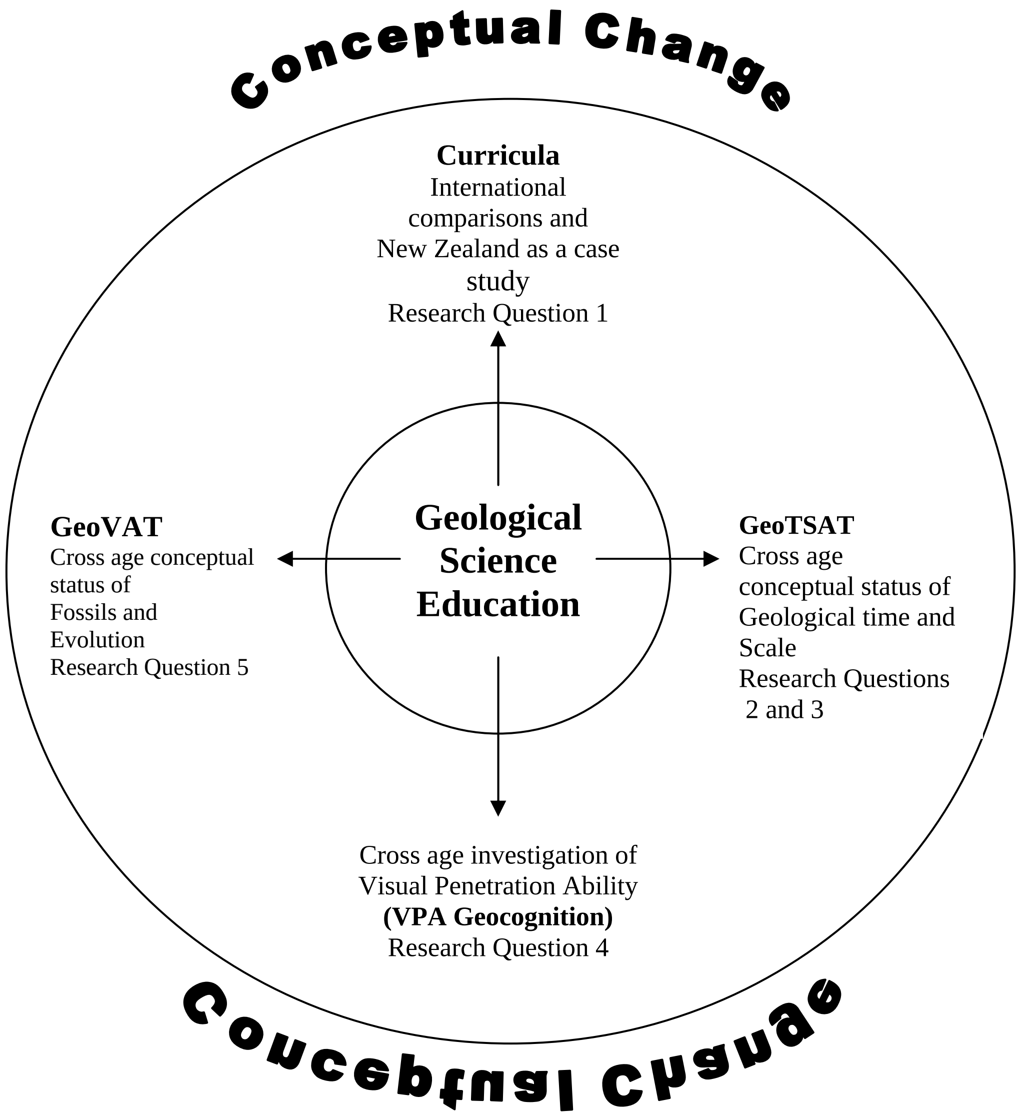


Figure 1.2. Thesis conceptualisation summary.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The purpose of this chapter is to provide the reader with a summary of the essential literature associated with the two key concepts addressed in this thesis and which largely defines geology: geological time and geospatialisation. These concepts are investigated and described in detail in chapters 6, 7, 8, 10 and 11). Developing conceptual and perceptual understanding of Earth's history (Deep Time) through scientific interpretation of macro and micro scale geological structures is a fundamental objective of geological education. Furthermore, the links between visual spatialisation of geological structures and time embodies the unique contribution that geological science makes to scientific literacy. In essence, geological education research is in its infancy with much to learn about the relationships between the neuro-cognitive aspects of time scale and space when related to geological structures.

2.2 Geological Time

A modern view of the cognitive aspects of time can be traced back to the Piagetian intellectual developmental studies of children during the 1950's and 60's (Piaget, 1952; 1969; Piaget & Inhelder, 1969) where developmental studies themselves are time or diachronically related in the sense of formative causative explanations for individual world views. Along with the application of time related studies in physics and astronomy such as gravity and Big Bang theories diachronic cognitive development is also implicated in our understanding of geological time. With diachronic thinking, Nicolaus Steno in the 17th century and James Hutton in the 18th century then gave the world an evidence based method for unravelling geological events in relative time. Understanding absolute (radiometric) geological time had to wait until the early 20th century. Following on from these early studies of child development the work of Zwart (1976) was influential in beginning further research into relational temporal cognitive development (later to become the diachronic thinking schema of Montangero and used by Dodick and Orion, 2003), where an understanding of time lies in the development of sequencing the 'before' and after' relationships of natural phenomena. Hume (1978) underscored the central educational value of knowing about geological time. It was thought that children organised geological time relationally. These underlying cognitive aspects of making sense of geological relationships were first investigated by Ault (1981) on children aged 3 to 8 years old and found that although these students were able to sequence strata relationally (Steno's law of superposition), they could not place these stratal sequences within a geological context. The research suffered form focussing on temporal sequencing itself rather than sequencing within a geological context. Friedman (1982; 1989; 1990; 2000; 2002; 2003) has built on the work of Piaget and has been influential in further cognitive research of how young children develop their conceptions and perceptions of time. Developmental studies opened the question of investigating the relationships between temporal cognitive development and knowledge based subject specific context. Dodick and Orion (2003a) point out the difference between geological event-based temporal sequencing and the cognitive processes underlying it. Studies by Noonan-Pulling and Good (1999), Marques and Thompson (1997) and Trend (1997, 1998, 2000; 2001a; 2001b) investigated the temporal sequencing of high school aged students. Trend in particular has shown how students ranging in age from 11 years to primary school trainees tend to lump time related events into categories that are easily related to a persons lifetime as extremely ancient, less ancient and recent.

An individual's conceptual knowledge evolves through time (See Chapter 6) and the development of an evocative memory is a prerequisite for diachronic thinking (Montangero, 1996). 'Thinking in time' and 'explaining in time' are rich areas for future research as applied to geological education. As Montangero (1996) demonstrates, by the age of 5 years children have already developed the cognitive knowledge that underlies being able to think diachronically and already have an understanding of past, present and future that enables them to reconstruct a sequence of events. What they don't have are the geological conceptual frameworks that allow them to make sense of relational, durational and scalar aspects of geological history. This requires carefully managed and well resourced learning experiences among which fieldwork is critical. Seminal research by Orion and Hofstein (1991) and Orion (1993; 2003) clearly show the importance of the linkages between seeing geological structures in the real macro world and its connection to temporal sequencing of geological events.

Recent work by Libarkin and Anderson (2005), Libarkin, Dahl, Beilfuss and Boone (2005), Dahl, Anderson, and Libarkin (2005) has shown that US college age students have little idea of the absolute age of the Earth and the scale of geological time in general. Many have a naïve view of how the age of the Earth is even worked out and the evolution of life. Through the development of a Geoscience Concept Inventory (GCI) Libarkin and Anderson (2005) confirmed the poor understanding of geological history and the time relativity of events that produced the observed geological evidence. Dahl et al (2005) even found that teachers were poor at using the laws of superposition and uncomfortable with dating geological events. These studies begin a new phase of research into geocognition and geological time based studies and suggests that future research needs to look at innovative ways of teaching geological time. Underlying much of the understanding of geological time is perception of scale. Recent research by Tretter, Jones, Andre, Negishi, & Minogue, (2006a) and Tretter, Jones, & Minogue, (2006b) point the way towards developing the teaching of scalar dimensions within a geological time context. Some of these aspects are fully discussed in Chapter 6. Useful literature reviews are to be found with Manduca and Mogk (2006) and Orion and Ault (2007).

2.3 Geospatialisation

As is so often the case in educational research, earlier work by Piaget and colleagues on child development (Piaget, 1952; 1968; Piaget, Inhelder & Szeminska, 1960; Piaget & Inhelder, 1967) has set the scene for research into cognitive spatialisation abilities. It was not until the late 1970’s that research into spatialisation abilities specifically within a geographic and geological mapping context was begun to be explored (Crossley and Whitehead, 1979; 1980). This established an early connection with place, space and geological structures within a field based context. Little published work on geospatialisation occurred through the early 1980’s although Piburn (1980) began his studies into geospatialisation that was to bear fruit twenty years later as part of the Hidden Earth Curriculum Project when computer assisted graphics became established and expanded (Piburn, Reynolds, Leedy, McAuliffe, Birk & Johnston, 2005; Reynolds, Johnson, Piburn, Leedy, Coyan, & Busch, 2005). Another centre of interest in geospatialisation developed in the late 1990’s in Israel where studies of high school age students’ spatialisation abilities were undertaken (Kali & Orion, 1996; Kali, Orion & Mazor, 1997: Orion, Ben-

Chaim & Kali, 1997). Kali and Orion (1996) were the first to investigate the uniqueness of visual penetration ability in the identification of and interpretation of geological structures. This requires what Kali and Orion (1996) call visual penetration ability (VPA), a unique feature of geological science and which is investigated and discussed in detail in Chapters 7 and 8. Kali's work also investigated spatial visualisation relationships with concrete models of structures as seen in the field and the effectiveness of the use of computer aided 3-D graphics for teaching geological structures Computer software was then developed to assist students in developing their 3-D perceptions (Kali, 2002; 2003; Kali, Orion & Mazor, 1997). The findings of the Hidden Earth Curriculum Project and the work of Kali and Orion indicate that well thought out and prepared software programmes do make a difference to learning 3-D skills and improves ability to interpret geological structures. Black, (2005) investigated spatial ability and geological conceptual understandings.

Geological structures are formed through time but the identification and interpretation of these remnants of geological processes depends on visual spatialisation abilities. These abilities are cognitively based on how the brain processes object information and the position of these objects within space: the so called ventral and dorsal neurological pathways Current geospatialisation work is grounded in neurocognitive research and investigates ways in which teaching can take advantage of new understandings of how the brain interprets the position of objects in space within a geological context (Blazhenkova & Kozhevnikov, 2009; Kastens, 2010). Geological objects such as large scale fold and fault structures have to be identified, located in space and interpreted from minimal (usually surficial) information. Significant recent work by Kastens, 2007; Kastens, Ishikawa & Liben, 2006; Kastens & Ishikawa, 2006; Kastens, Agrawal & Liben, 2009.) has steadily increased our understanding of visual spatialisation skills within a geoscience and geological context. Manduca and Mogk, (2006) provide a useful summary of the key elements to spatial thinking and directions for future research into this important aspect of geological (and geoscience) thinking.

The following sections of this chapter outline in detail critical aspects of what the literature says about geospatialisation and geological time, the two key aspects of geoscience education addressed in this thesis.

2.4 Development of Conceptions of Time

Friedman (1990; 1982; 1989; 2000; 2002; 2003) has carried out many investigations into the child's development of the perception of time through investigating how young children one to five years old perceive unidirectional transformations involved with gravity and time. Figure 2.1 summarises the age related conceptual status for understanding about time.

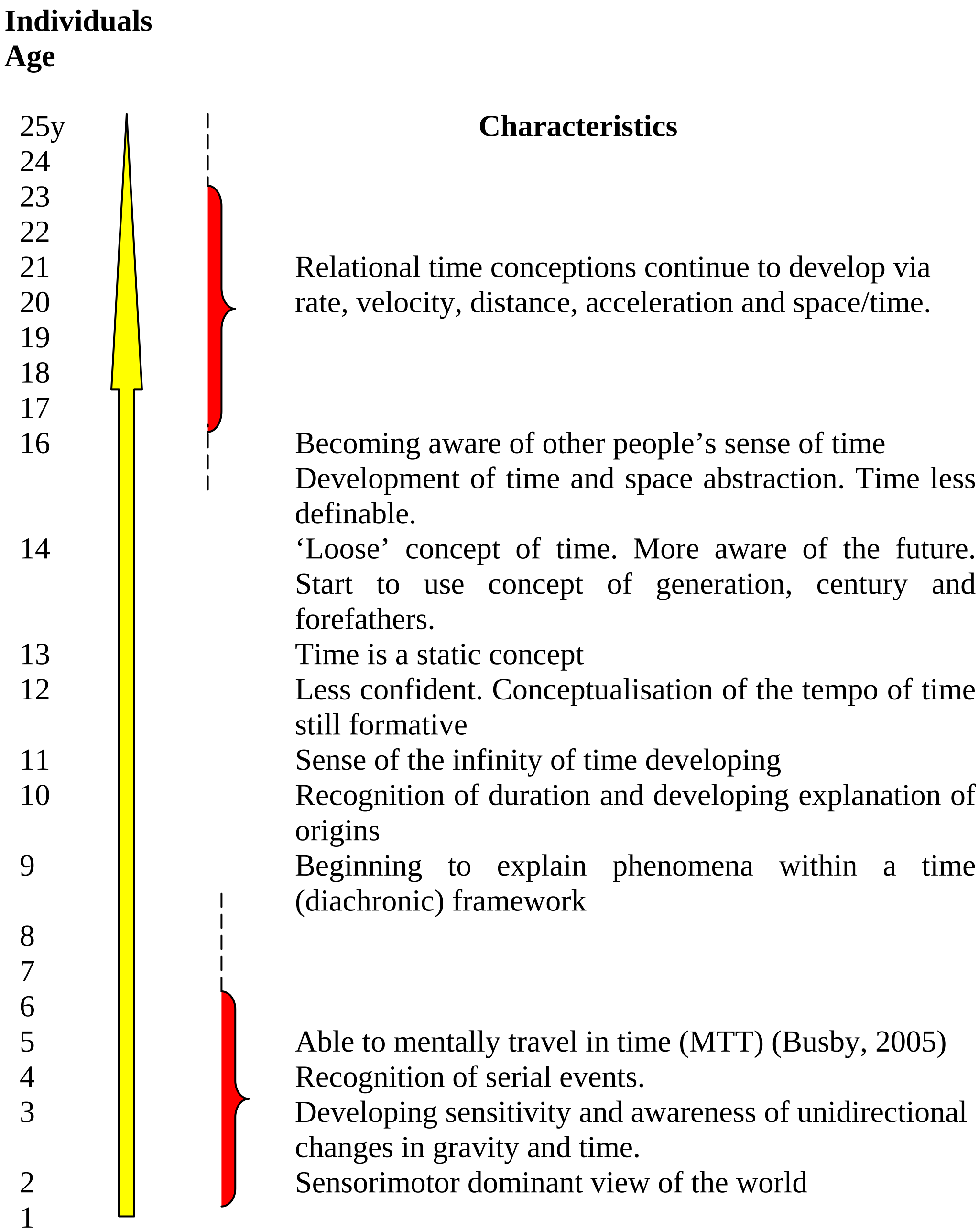


Figure 2.1. Chronological age conceptual status map for 'time'
[after Ault (1981), Friedman (2003) and Langone (2000)]

In Piaget’s progressive ‘stagist’ mechanisms of arrow like progress towards the formalisation aspects of adulthood, the child conceives time as “a co-seriation of successive spatial states” (Piaget, 1969).This is a relativistic conceptual view of time and Piaget considered the child’s conceptions of time to be complete by about the age of ten. If only things were that simple. In 1927 when Piaget wrote about the child’s conception of time a modern appreciation of geologic time was only just emerging and the impact of plate tectonic theory, geochronology and geophysical techniques were still 30 years away. Indeed, Piaget did not investigate conceptual development of the child’s view of geologic time and he was limited by assumptions about a child’s strong connectedness between motion and time.

The geological sciences depend on an understanding of fixed physical rock exposures and fossil content for any understanding of relative geological time rather than connection with physical motion and counting durational time. Studies of student thinking about geological time are also constrained by the gap between individual knowledge and conceptual understanding. The relational concept of ‘older and younger’ is perhaps more important than durational geological time from a constructivist point of view. Ault (and Piaget) did not investigate the conceptualisation of ‘deep time’ (Dodick, 2007, 2003a). Understanding how geologists use and conceptualise geologic time requires teaching interventions to produce conceptual change understandings of geologic time from a serial view to a relational and durational view.

According to Ault (1981) children by the age of ten are able to infer relative ages of layering but only rarely within a rock outcrop exposure context in the real world. At age ten, when children were confronted with rock exposures in the field, they equated age with the physical and surficial characteristics of the layers rather than relative position in the stratigraphic column. Young children apparently recognise layering but not in a relational sense. Indeed, at age 14 years (and beyond) a concept of relational time is still very developmental and it is only by age 18 years and exposure to adequate training in geology that relational aspects within geological contexts become confirmed.

Recent findings by Busby and Suddendorf (2005) support the conclusion that “the ability to recall past events and the ability to predict future events (i.e., mental time travel) emerge in tandem between the ages of 3 and 5 years” (Busby & Suddendorf, p. 362). Younger children (<3 years old) may have different understandings of the terms yesterday, today and tomorrow but may still be able to mentally travel in time. Clearly then, a formative perception of relational time is established very early on in child development and Busby and Suddenndorf’s evidence shows that young children are able to mentally travel in time. The ability to mentally travel in time is essential for future mental development of geological time. The temporal mechanisms by which geological time is organised and understood involves experience and practice of the principles of geological strata relationships. The ability to mental travel in time is dependent on attributes such as “recursion, self awareness, metarepresentation and the ability to dissociate current from imagined states” (Busby & Suddendorf, p. 363). Furthermore, there appears to be no gender difference in the ability to report on time related events such as those events having occurred yesterday, those today and those in the future and at the tender age of five. Interestingly, it is not until the early teens that an apparent sense of the infinity of time begins to develop.

Montangero (1992; 1996) has developed a model for diachronic thinking; a model indicating how process schemes interact to help form a web of conceptualising time. Figure 2.2 shows a conceptual model of the major underlying variables involved in understanding time. These schemes of transformations, temporal organisation, linkages and synthesis form the cognitive basis in which time is perceived and utilised in understanding the world. It is unfortunate that the link with geological (deep) time has not been intensively investigated. Indeed, Dodick and Orion (2003) point this out as a limitation to Ault’s (1981) work. In Montangero’s model of diachronic thinking, the processes of transformation involve an individual’s observation and recognition of changes and differences in natural phenomena. Change implies time dependence, and it appears that awareness of unidirectional change begins to develop about the age of four (Friedman, 2000). Geo/biological events mark movement in time. Transformative recognition of geological change is based on the principles of ‘uniformitarianism’ and ‘actualism’. In this sense, uniformitarianism and actualism are considered close relatives of one another whereby interrelated geological processes operating today provide a key to scientifically unlock the past history of the earth in geological and biological contexts. Indeed, the history of uniformitarianism and actualism are instructive conceptual change notions about geological time which are closely bound to the history of geology, the concept of catastrophism, and Charles Lyell and the Darwinian revolution in understanding connections between geological and biological events.

Essentially, by the end of the nineteenth century, geological thinking (built from Hutton's earlier, 1785 ideas), was dominated by Lyell's uniformitarianist concepts of geological history and anti-catastrophist. But uniformitarianism (in terms of uniformity of process), failed to take cognisance of rates and duration of time (Lyell took it that rates of geological change have always been the same even though he recognised recent historical differential rates of change). This implied a concept of a steady state and cyclical earth history where it was the cyclical nature of change that was considered real. In Hutton's immortal words *"no vestige of a beginning - no prospect of an end"* (Hutton, 1788), the Earth simply recycled itself (even though a mechanism was not known at that time and plate tectonic theory was still about 180 years in the future).

In an effort to overcome the non-progressivist nature of Lyell's unformitarianism, the concept of actualism was invented to account for differential rates of change that act under physical constants and unchanging laws of nature. In other words, rather than fixed and uniform geological processes, it was the 'laws' of nature themselves that were unchanging and which governed rates and durations of observable and measurable geological events and therefore time. The problem was (and is?), what is meant by "constant" and is this really a controlling constraint for understanding geological history? According to Gould (1987), 'actual' in most European languages means 'present' rather than 'real' (as in English), and from which the geologists' dictum, "the present is the key to the past" is derived. Actualism is what Gould (1987) defines as "the so-called principle of simplicity: don't invent extra, fancy, or unknown causes, however plausible in logic, if available [geological] processes suffice" (p. 120). This is an important application of 'Occam's razor' to geology because it enables the most parsimonious inductive explanation of field observations and measurements. Montangero's transformative and constructive learning processes to an understanding of geological change occur through concepts such as uniformitarianism. From this concept came the concept of the rock cycle - a key concept in understanding change and time. Trend (2005), however, sounds a warning when "research suggests that failure to grasp the concept of deep time can become a barrier to children's and teachers' further engagement with geoscience" (p. 372). Furthermore, Trend suggests that a scientific appreciation of geological time and its links with environmentalism and earth systems may be crucial to an understanding of our planet's future. Certainly, Orion and Fortner (2003b) clearly show these linkages and the importance of connecting the 'real world' of field geology with the 'indoors' learning world.

The ability to correlate (geologically) is a cognitive diachronic process of temporal organisation and is essentially controlled by age, experiences and training. Geological correlation of geographically separated rocks as belonging to the same age is based on comparing fossil content rock strata relationships. Question one in the GeoTSAT questionnaire gathers information on the temporal organisational approaches in identifying correlative rock layers. Montangero's interstage linkage is the 'glue' that binds and connects temporal organisation with transformative process. These linkages are constructivist in nature and developmentally controlled (Dodick & Orion, 2003a; Montangero, 1996). Montangero (1996) points out that "The generalisation of the idea that apparently immutable things have an origin thus appears at the same age as the emergence of an advanced type of diachronic thinking, that is to say about the age of ten." (p. 75). By the beginning of secondary school (at around the age of 13), students have assimilated (but not necessarily accommodated) adult concepts and explanations and often begin to incorporate them into their own worldviews. Indeed, the fact that at this age, for example, students refuse to "apply a familiar schema to the question of the origin of the universe" (Montangero, 1996, p. 75) supports the idea of conceptual change occurring within a diachronic framework in a 'Vosniadouian' type fashion. That is, without learner intent and intentional teaching, exposure to different conceptual explanations of geological phenomena less effective conceptual change would occur. Diachronic thinking is thinking across and through a perception of time. The key elements involved with diachronic thinking are synthesised in Figure 2.2 and are derived essentially from Ault (1981), Montangero (1996), and Dodick and Orion (2005).

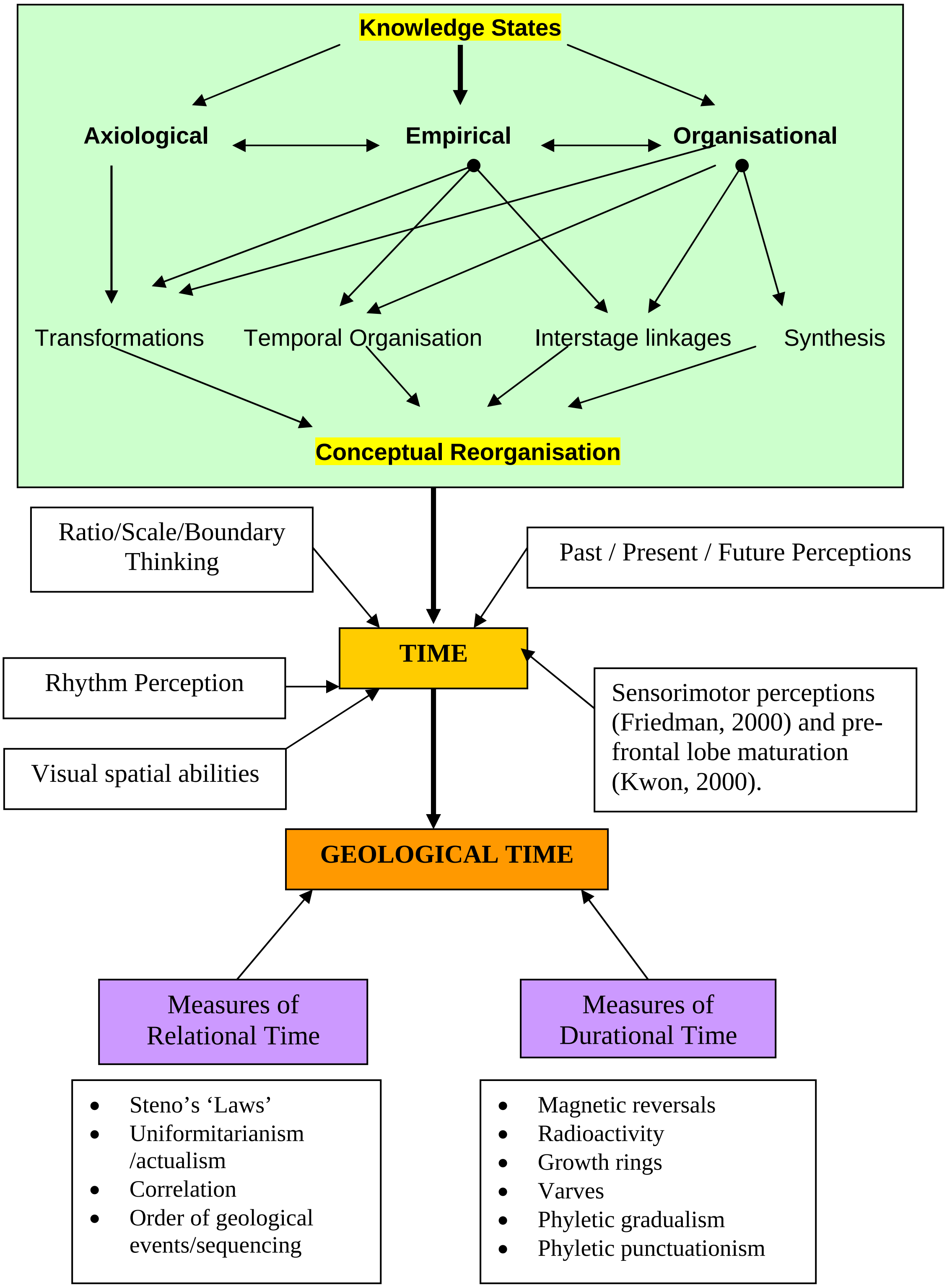


Figure 2.2. Conceptual ecology map for understanding diachronic thinking. [After Ault (1981) Montangero (1996) and Dodick & Orion (2005)]

Indeed, intention generates engagement and without intent learning does not happen. Intention is also somewhat controlled by interest, attitudes, values and perceptions both by teachers and learners (Vosniadou, 2003, 2007a; Vosniadou, 2007b).

> *We claim that instruction-induced conceptual change requires the deliberate use of top-down, intentional learning mechanisms to be achieved.* (Vosniadou, 2007b. p. 50)

Montangero's temporal organisation scheme defines the steps involved in making sense of a transformational process such as the use of the principle of uniformitarianism in understanding geological history. It is an evolutive learning process in which conceptual transformations are understood and applied. Geological time is understood through empirically derived and tested organising ideas such as Steno's Laws explaining rock strata relationships, correlation, chronostratigraphy using radioactivity and magnetic reversal data and biostratigraphy. Biostratigraphy is the use of index fossils to define periods of time in the geological and fossil record. The geological time scale in use today is an end point of temporal organisation: a point in which Montangero (1996) would consider a dynamic synthesis defining "the development of a field as a *single* conceptual reorganisation" (p. 170).

Human beings are very good at conceptual reduction but in the process forget or miss out the details and worse, add-in irrelevant or incorrect ideas. This is what makes the teacher's job complex and difficult. Establishing and changing conceptual understandings is not easy. It seems that to make sense of the world conceptual reduction or simplification of a concept to a dichotomy is necessary. It is intellectually easier to reduce conceptualisation to yes/no, black/white, right/wrong, primitive/advanced and just and unjust. From a structuralist point of view, it makes sense for survival to reduce conceptualisation to the minimum – the details can be argued about later. From a learning point of view, it makes sense to reduce ideas (especially new ideas) to cognitively manageable levels. Steven J Gould (1987; 2002) had a lot to say about dichotomies but is best summed up as stating, "dichotomies are useful or misleading, not true or false. They are simplifying models for organising thought". (Gould, 1987, p. 9). The uniformitarianism/catastrophism dichotomy is a key dichotomy in geological thought not only in the history of western science and philosophy but also in the evolution of thinking about geological time and earth history. Deep Time as a western philosophical construct was embodied in the ideas of repetitive cycles and directional arrows with progression from primitive to advanced, young to old and right from wrong. The negative influence of Judeo-Christian thought about time had, until Steno, Hutton, Lyell and Darwin, held centre stage and it is only fundamentalist groups today who still cling to the idea of literal religious thought. Formative teenage minds (and untrained teachers) unsurprisingly find the complexity of Deep-Time and the evolution of life all too difficult without recourse to exaggerated and naïve dichotomous simplification. In a sense, dichotomies are a 'brain wired' dynamic synthesis (in the Montangeron model) where forming a whole "single process of change" from a set of successive stages occurs. It is little wonder that teaching and learning about geological time is a challenge to educationalists and learners.

It can be argued that geology uniquely provides a transformative learning mechanism for the development of diachronic thinking and its application to a conceptualisation of what McPhee (1981) first described as 'Deep-Time'. In an unpublished report as part of a Royal Society (NZ) teaching fellowship, Vallender (1997) investigating Earth Science education in New Zealand, found that out of 90 first year university geology students (aged 18-19 years and effectively before any geological training), 57% did not know the scientifically accepted age of the Earth of 4.6 billion years. Out of 30 primary and secondary school teacher trainees, only 50% knew the age of the Earth. Typically, first year students at university and teacher training college were also naïve about how relative dating works (by correlation of rock layers) and were suspicious of radiometric dating techniques thinking that the only kind of radiometric dating technique was carbon dating. Chapter 9 discusses in detail several aspects of the New Zealand Science curriculum that impact on this kind of thinking about geological time. Essentially students are just not sufficiently exposed to an understanding of radiometric dating technology and its triangulation with other dating techniques.

As previously mentioned, research by Trend (2000) suggests that primary teacher trainees in the United Kingdom conceptualise the geological past in distinct clusters: extremely ancient, less ancient and recent. Furthermore, Trend suggests that it is ignorance of the geological timescale and relativity of key global geological events that retards the conceptual understanding of ‘deep time’. Key geological events which mark the passage of time include the fossil record, periods of mountain building and eustatic sea level changes. Results in this thesis corroborate this point of view.

Perhaps these students had also not been exposed to diachronic thinking in a geological context? Dodick and Orion (2005) accurately point out that Montangero’s schemata for diachronic thinking provides an evolving cognitive model for developing diachronic thinking about geological time.

2.5 Thinking About Scale

Conceptualising scalar dimensions is fundamental to a scientific understanding of our world and our place in the universe. Indeed, making sense of geological time is very much dependent on building conceptions and developing perceptions of scale (AAAS, 1989). Dimensional scale is viewed as an important unifying theme: wherever one goes in science, there is the problem of scale. Gould (2001) makes clear the point that an understanding of scale is persistently related to the human body in space and time. For example, when a class of students of 13 and 18 years were asked in an informal classroom situation to describe five seconds, they used a relative scale of length often physically using hands to measure a length and then scaling five seconds into this length. It was interesting that no one used a relative scale of mass – it seems that time is conceived as a linear length scale. In contrast it seems that when distances become too large (eg distance from Perth to Auckland), for a relativistic comprehension, scale is switched into a time scale so that distances become times (Tretter et al. 2006). In other words, one does not state the distance from Perth to Auckland or Hong Kong to London in kilometres, but in time. Perhaps this phenomenon indicates a neuronal tipping point from relativistic perceptions into that part of the brain dealing with calculations (Kunzig, 1997; Paivio, 1986) and relativism. Paivio (1986) suggested that the ability to conceptualise the very small and the very large (including time and in particular geological time), an individual lacks the experiences at these extreme ends of dimensional scales. Without experiences, spatial information simply cannot be stored (and then retrieved) in the brain. Experience is needed to place geological time into an individual’s preconceived and preformed scaling systems. Similarly, Deheane (2002) suggested that size may be represented in a similar way to number. Figure 2.3 is an attempt to summarise the connections between conceptualising and perceiving scale within our world.

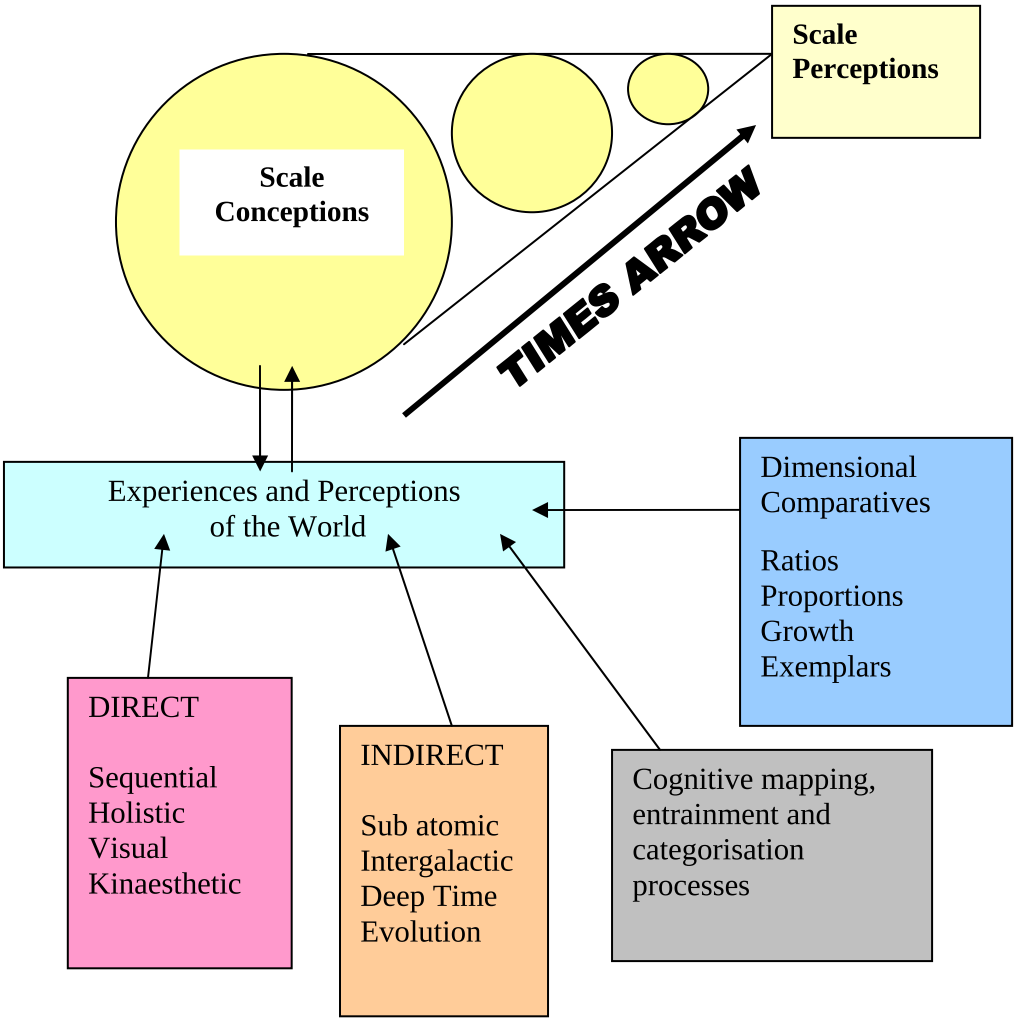


Figure 2.3. Factors influencing conceptions of scale (after (Tretter, 2006).

A different conceptual leap is required for perceiving geological time compared to linear dimensions, where both distance and time are beyond a calculable value and a relativistic comprehension. To speculate, the subatomic world seems to be a conceptual scaling leap that is likely to require scale experiences that go beyond the experiential time of a high school student. Providing meaningful opportunity for these experiences is the teacher's challenge. Yet secondary teachers insist on teaching 'the atom' and the 'ion' to students at age 13-15 years, and anecdotally, teachers often wonder why their students "don't get it". Clearly, high school age students (and many beginning college age students) seem to think mostly in relativistic time durational terms. In other words, whatever scalar and spatial view individuals have of the world, it is relative to their bodies, and in particular, for geological time, the span of a human lifetime. After all, a single healthy human lifetime is only about 0.0085% of a million years and one million years is only 0.02% of four and a half thousand million years! Little wonder that the seventy one million year duration of the cretaceous (0.158% of earth history) is misunderstood and not comprehended. What is your concept of 0.0085% of a million? At what point on your mental number line (Kunvig, 1997) does your comprehension of 0.0085% become meaningful or meaningless? And yet for geologists, conceiving scales of time in a meaningful way is a fundamental attribute in making some kind of sense of Deep-Time and earth history. Table 2.1 attempts to show the geological connections with the direct experiences required for making sense of scale in the geological world.

Table 2.1. Experiences and geological time correlatives.

Experiences (see Figure 5.3)	**Geological Time Correlatives**
Sequential (seriation)	Relative order of geological events Correlation Steno's Laws
Holistic	Earth History (local and global) Naturalism
Visual	Rock outcrop exposures Spatialisation, visual penetration ability Fossils Natural hazards –earthquakes, volcanoes, tsunamis, floods, droughts, landslides.
Kinaesthetic	Feeling and holding fossils as representatives of 'Deep-Time', rocks and minerals. Touching rock outcrop exposures; touchstones.

The challenge for teachers of geology is to provide meaningful direct experiences for students to learn about the scale of geological time. Techniques that provide comparative experiences of time ordered phenomena such as geological field work through a stratigraphic column or physically measuring time through techniques such as growth ring analysis may be a step towards this goal.

Fieldwork is not only an essential element of geoscience education and clearly an important technique for developing skills and perceptions (Drummond, 2001; Kern, 1986; Orion, 1993, 2003a, 1997; Plymate, 2005; Riggs, 2003) but is also crucial to blending and developing indigenous peoples' understandings of the natural landscape (Riggs, 2005). Studies show (Orion, 1993) that there is a clear advantage for students being exposed to the real world through investigative application types of fieldwork as opposed to a 'look and see – back in the bus' type of approach. The challenge for teachers (at all levels) is to develop manageable, cost effective and conceptually meaningful field experiences for geoscience education. Recent work by Clary, Brzuszek, and Wandersee, (2009) indicates another way of making powerful learning connections about geological time by having students develop conceptual statements and conceptual mapping within an informal educational setting outside the classroom.

Trend's work (2001) on investigating how geological time is conceived by 17 year olds (and this thesis, Chapters 10 and 11) suggest a strong connection between time scale and distance scale. Indeed, this suggestion was supported in recent work by Hardin, Jones and Figueras (2005) where a strong connection between distance and time categorisation was found. However, merely being able to correlate distance scales with a time scale is very different from correlating distances and size with geological time. Understanding geological time is beyond most individual experiences and this helps explain why, in Ault's (1981) work, children were able to conceive relative time but were unable to transfer this ability to the real world at a geological rock exposure in the field. Trend (2000) also found that geological time, as represented by geological events, was conceived by primary teacher trainees as falling into three large categories: extremely ancient, less ancient and geologically recent. It seems that some kind of 'cognitive lumping' occurs when the mental timeline scale (and other scaling categories in the brain) can not accommodate values outside relativistic experiences. Table 2.2 presents some possible scaling categories with geological time as unimaginably ancient.

Table 2.2. Some possible scaling categories.

Mental Time Travel	Size	Numbers
Unimaginably ancient	Unimaginably small	Unimaginably infinite
Extremely ancient	Atomic	Minus three
Ancient	Very small	Minus two
Recent past	Small	Minus one
NOW	ME	ZERO
Near future	Large	One
One life time	Very large	Two
Future	Huge	Three
Unimaginable future	Unimaginably large	Unimaginably infinite

2.6. Conceptual Development of Geospatialisation

Understanding complex geological structures that have been produced by multiple deformation episodes is largely dependent on an observer's ability to visualise these structures in 3-D. Modern efficient software construction of 3D maps and diagrams may have crucial importance in the economic development of a mineral rich geological structure and also enables deciphering of the geological history of an area. This chapter investigates the importance of spatialisation and describes results from pen and paper exercises in the GeoTSAT instrument. Much of our understanding of the development of spatialisation skills stems from the early work of Piaget and Inhelder (1967) and developed further especially by Siegel and White (1975), Seddon, & Shubber, 1985, Vandenberg, 1978 and many others. It was not until the mid 1980's that spatialisation abilities began to be applied to the geological sciences. According to Devlin (2001), a key developmental stage is the pubertal concrete stage transition to projective and Euclidian visual spatialisation. Results reported in this thesis straddle this age boundary and beyond.

The ability to spatially visualise is fundamental to an understanding of the geometry of objects and the physical space we inhabit. Survival depends on the ability to judge distances, anticipate directions and visualise objects in 3-D space. We are part of space and volume. Spatial abilities are also implicated in visualising molecular structures, engineering structures, gaming and modelling. Spatial ability is an important intelligence and in chemistry, for example, recognition of molecular shape, identification of p-orbital's and rotation about carbon bonds is an important ability for a deeper understanding of molecular structures and consequent properties (Coleman, 1998). Similarly, in the teaching and learning of biochemical molecules spatially visualising DNA, for example, is important for developing perceptions of gene locations, mutational changes and genetics. Similarly, the ability to spatially visualise protein molecular shapes is important for a better understanding of how proteins can catalyse reactions. In the medical sciences the development of MRI and CAT scans require visual spatialisation abilities for accurate diagnosis and development of treatments. CAT scans and x-ray scans are routinely used for example, in penetrating hidden structures such as fossil dinosaur bones in eggs. X-rays are also used in the investigation of archaeological sites especially those of cultural significance.

Geological structures often display distorted rock strata, and the ability to predict extensions of strata into the unseen 3-D space is a skill that has been used by miners for centuries. Baldwin and Wallace (2004), along with other researchers (Ben-Chaim, 1988; Black, 2005; Broadfoot, 1993; Kali, Orion, & Mazor, 1997, clearly point out the importance of spatialisation abilities to the understanding of geological structures as a means of interpreting structural histories. Black (2007) succinctly points out that spatialisation in its many forms is a crucial element in the design of Earth Science curricula and that a deeper understanding of this ability would help address many conceptual difficulties. Along with the teaching of graphic design and geometric aspects of mathematics, teaching geology may provide unique opportunities for teaching spatialisation skills. Teaching spatialisation in a geological context is unique in the sense that geological structures such as domes, anticlines and synclines are placed in a historical geological time perspective. No other subject can do this. Figures 2.4 and 2.5 shows typical large scale fold structures that geologists are often confronted with in the field.

Figure 2.4 Anticline.

Figure 2.5. Syncline.

Field experiences in geology courses can provide a connection with 3-D spatialisation that no other subject of learning can provide. Orion (1993) clearly shows the links between success in geology and exposure to fieldwork but actually measuring the influence of field experiences on the development of spatial abilities is difficult due to the complex interacting nature of variable learning experience (Orion, 2003a) and the social novelty attitudes of students when placed in the field. Typical Biology fieldwork exercises for example, focus on two dimensional surficial distribution aspects rather than connection with a three dimensional world. An example of this is a typical lawn study where distribution of plant species is observed. The time aspect of growth and succession is often deemphasised in biological fieldwork in favour of observing distributions. Indeed, anecdotal and personal experiences with Year 12 (age 16/17 years) students in a forest environment indicate that students of this age often have difficulty connecting depth, and height. Forest stratification exercises for example, suggest a difficulty with perceiving species layering (strata) even when immersed and being a part of the forest. Students often see only the 2-D layering and disconnected from a forest volume. A question worth future investigation may be student visualisation perceptions of forest bird predators such as Eagles flying in a three dimensional forest. Even more so, visualising many other species in three dimensional interacting space webs is likely to be even more difficult for the majority of this age group to conceptualise and perceive.

Orion, Ben-Chaim and Kali (1997) report significant improvements in spatialisation ability after field work training, but it is difficult to tease out the precise interactive contribution between field learning and all other simultaneous learning in other subjects. In other words, learning spatial orientations is more complex than single correlations between fieldwork and observed geological structures. Translations of various scales of distance and orientation are an important aspect of conceptualising natural geological structures. For understanding geological structures it is desirable to expose students to a wide variety of learning experiences which are linked to the real world outside the classroom (Marques, Paria & Kempa, 2003). This means that for geology, field relationships investigated within a 'natural real-world field' perspective, rather than in the virtual digital world, have a powerful influence on the cognitive development of spatialising geological structural relationships. However, the power of modern digital modelling and graphic rendering such as programmes like The VR Worx 2.0 [Computer Software] (Kali, 2002), and the VR Toolbox Curriculum (http://www.vrtoolbox.com/educators/educators.html) enables the 3-D treatment of geological problem solving and can provide unique perspectives which enable us to 'see beneath our feet'. Other software programmes such as *Geo3D* (Kali & Orion, 1997) have been specifically developed for teaching aspects of structural geology which requires visual penetration ability (VPA).

Figures 2.6., 2.7 and 2.8 illustrate the ability of modern computerised graphic rendering and Geographic Information Systems (GIS) to present 3-D visualisation of geological structures.

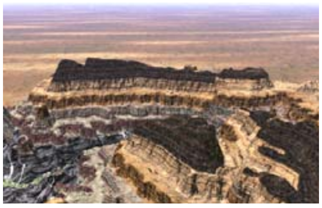


Figure. 2.6. Cropped graphic selection from Piburn et al. 2002.

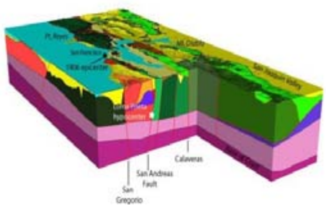


Figure. 2.7. USGS 3-D picture of San Francisco geology.

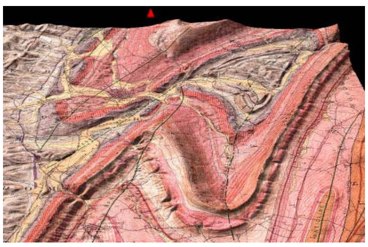


Figure. 2.8. Surface expression of folds
(http:// reynolds.asu.edu/geomap3d/gm3d_hollidaysburg_n.jpg.)

The power of 3-D imaging is found in enabling the observers' ability to visually penetrate through animation and to be able to 'see through and round corners'. The ability to control rotation of images enables trained personnel to visualise subsurface geology that is only just being made available to local and national planners. The application of 3-D geology imaging has enormous potential for mitigation of potential natural disasters and is a clear link with 'systems thinking' where integration of disciplines such as computer graphics, geographic information systems and geology interact. But its potential is dependent on trained conceptual understanding of spatial visualisation of geological structures and the gathering of accurate field data. However despite the power of rotational manipulation and animation onscreen, maps and diagrams on a computer screen do not and can not convey the sense of geological time and scale that can only be appreciated in the field by those with relevant academic training. In observing a geological outcrop, trained geologists appear to differ from learner geologists in their approach to outcrop interpretation Kastens, Ishikawa and Liben (2006). In the field, experts use spatial information to investigate the relationships between rock strata patterns whereas untrained learners do not. Only when learners are provided with scale models of the geology of an area that they begin to think spatially (Kastens, Agrawal & Liben, 2009).

According to Kastens et al. (2006) "many participants' difficulties with the task seem rooted in their failure to perceive or record the kinds of spatial information necessary to solve the posed problems, rather than in their difficulty in integrating the spatial information in hand" (p. 425). Perhaps this difficulty also indicates the importance of the need for development of concepts of scale (i.e. real world field scales versus the table top model world), before developing concepts that can be combined into a workable 'geological' view. The fact that novices in the Kastens et al. study concentrated on the rock exposure in front of them and failed to make spatial comparisons with physical surroundings when in the field, perhaps suggests that they were unaware of the scalar differences or were unable to relate these scalar differences from the laboratory to the field. Perhaps these novices also lacked the confidence for interpreting a single outcrop yet alone its relationship with the 'wider world'. Besides, how do they know that a single outcrop is actually connected to the larger scale geological structure being observed? Perceiving and conceptualising the hidden view of the Earth is difficult without having planned learning experiences.

Research by Hegarty, Montello, Richardson, Ishikawa and Lovelace (2006) and others (discussed below), suggest that amongst several models, a partial dissociation model (i.e. large scale and small scale spatialisation are not completely cognitively separated) (Figure 2.9), best explains an individuals' perception of the relationships between large scale (geological outcrops in the field) and the small scale (laboratory models). The ability of experts to transpose spatial information at a small scale to the larger scale (and vice versa) may help explain why experts in Kastens et al. (2009) work use spatial information and novices do not. Designing teaching strategies that assist in the development of this ability (Ishikawa & Kastens, 2005; Kali, 1997, Kali et al., 2002, Orion, 1993, 1997, Piburn et al., 2002; Reynolds, 2002, Kastens et al., 2006; 2009) is a challenge for secondary school geoscience and geography educators but especially so at undergraduate level. Investigation of the cognitive development of visual penetration ability remains a rich area of future research. What controls the overlap and is it 'teachable'?

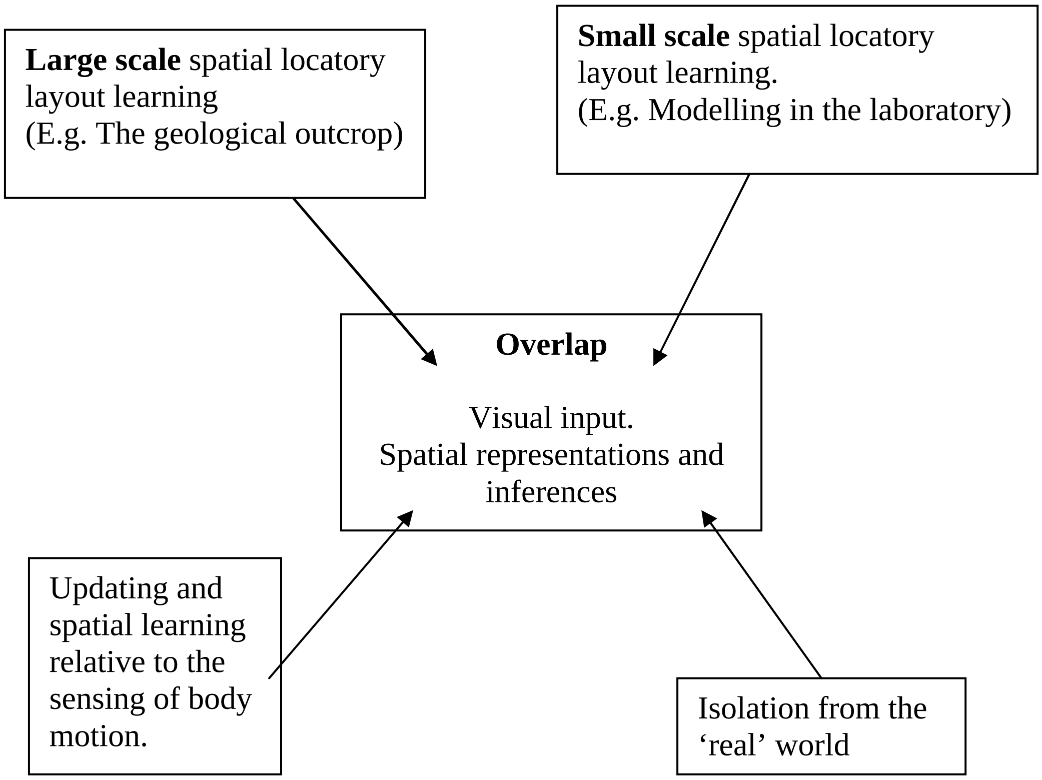


Figure 2.9. A partial dissociation model of mapping spatial ability (After Hegarty et al., 2006).

2.7 Visual Penetration Ability (VPA)

Early attempts by Zavotka (1987) and Bezzi (1991) using computer software indicated that spatial abilities can be improved with appropriate teaching techniques, although Black (2005) offers a caution in that much more research is needed to identify the nature of any improvements and what connections there are to teaching and learning. For example, although Black (2005) found that mental rotation ability was the best predictor of scores on earth science concept (ESC) tests, there is little research completed on visual penetration ability. This is a primary concern for visual spatialisation of geological structures. Notwithstanding this, using Linn and Petersen's (1985) classification of spatial abilities, visual penetration ability would include aspects of both visual perception and visual spatialisation. For example, according to Linn and Petersen, visual perceptions include the "overcoming of distracting cues". Evidence by Kali and Orion (1996) and confirmed in this study of simple tests of visual penetration ability for geological structure models and diagrams (see Chapter 7 for details). This is because students dominantly rely on seeking answers from exposed external surfaces as they are generally unable to visually penetrate the structure. In other words, their visual *perception* ability in overcoming distracting cues is the most common difficulty when dealing with geological phenomenon. However, there may be significant issues associated with the visual translation of 3-D block diagrams represented on 2-D paper. Few spatialisation studies deal in any depth with visual penetration ability (VPA). This issue is also addressed in Chapters 7 and 8.

Later efforts by Kali (1997; 2002) has extended efforts on software development for teaching spatial development for geological structures. The "GeoWall system" is a new technology that enables projection of stereographic images that can be viewed by students in 3-D (Anthamatten, 2006) and has been developed for use by geography students in aiding learning in cartography and geographic information systems (GIS). The full potential of this method of viewing geological structures in 3-D is yet to be seen and it is likely that costs, training and accessibility will be controlling factors.

Perceptualising and visualising, for example, the effect of faulting and rotation superimposed on folded geological structures is a spatialisation problem unique to the study of geology and much is still to be learned about how this ability works and how it can be trained and developed. Developing 3-D software programs that are manageable and pedagogically meaningful presents a challenge to the teaching of structural geology, and geomorphology.

Kali, Orion and Mazor (1997) divided spatial skills into two categories of manipulation of two or three dimensional objects and computer graphics of 3-D objects. Student spatial visualisation was based on previous work of McGee, (1979), Linn and Peterson (1985), Ben Chaim et al., (1988), Bezzi (1991) and Broadfoot (1993). Kali, (2003) continued efforts to provide software for student conceptual development of the rock cycle and its inherent systems thinking. However, the links between use of virtual 3-D software for conceptualising the rock cycle and the required degree of conceptual shift (especially in terms of the need for systems thinking and integration) has yet to be evaluated.

In the 2007 New Zealand curriculum document for Science education (Education, 2006), the rock cycle concept only appears at the Science curriculum level five (student ages of 13 to 14 years) achievement objective as an **implied** part of "Earth Cycles: Investigate the processes that shape and change the surface features of planet Earth". From a Geoscience curriculum perspective it is even more intriguing that subsequent revisions of this 2006 draft consultative document do not acknowledge the rock cycle in the curriculum at all (see Chapter 9 for details).

However, for geological studies, visual spatialisation skills are important in developing scientific concepts of how the rock cycle is interconnected with Earth's structure, composition and history. Indeed, geologists are required to envision distorted and often geographically isolated rock outcrops in their original form to derive a geological history. It is hardly surprising that it took a long time for geological histories of the European Alps and the Southern Alps of New Zealand to emerge from complex geometries produced by multiple episodes and different directions of forces needed to distort originally horizontal layers of rock that were once buried 20km below present sea level.

A small study conducted by Titus and Horsman (2009) on spatial visualisation in the geosciences included some material on visual penetration ability. In this study it was found that there was little difference between male and female VPA with females often outscoring males. It was also found that practice significantly improved performance on all types of spatial problems giving support to Piburn et al's. (2002) findings.

2.8 Diachronic Thinking and Spatialisation

The ability to think spatially and visually impacts greatly on an individual's conceptual world view and is also implicated in the cognitive development of diachronic thinking (Dodick, 2003). Investigations of organisational-temporal-diachronic relationships which develop in young children aged 8 to 12 years, (Montangero, 1996) suggest that the ratio of spatio-temporal solutions to spatial problems which involves decision making of a person's place in space and time, tends to increase with age. Without an ability to observe and mentally manipulate objects in space, the organisational structures of diachronic thinking (see Chapter 3), and the making sense of geological observations cannot happen. This in turn impedes construction of geological histories that are based on the stratigraphic and cross-cutting laws of superposition.

According to Dodick and Orion (2006) extracting geological histories based on correlation (giving equal age to geographically separated rock strata), requires a spatial-visual demand that is greater than that required for perceiving superposition based on stratigraphic age order alone. Superposition simply requires knowledge and comprehension of 'oldest bed at the bottom' in a vertical sequence of strata (assuming strata have not been overturned) whereas correlation requires visualisation of strata from different localities and landscape cues: a spatial visualisation problem unique to the geological sciences. Further testing by Dodick and Orion suggested that geological correlation of strata requires "the highest level of visual-spatial thinking in order to temporally order its contents" (p.11). This kind of visualisation skill involves perception, rotation, visualisation and penetration especially where rock strata is contorted and requires 'matching'.

Most diagrams in books are two dimensional but the ability to three dimensionally 'match' correlated strata requires a much higher order of thinking. Actually visualising stratigraphic relationships in the field or even by aerial photograph is a prerequisite for gaining an enhanced understanding of local (and global) earth histories. The folding and faulting of rock strata holds many secrets to the multi origins of landscapes and what lies beneath our feet. Neither Piaget and Inhelder (1967), Black (2007), Dodick and Orion (2006) nor Piburn et al. (2006) investigated visual penetration ability of geological structures. Indeed, Black's (2005) work on spatial ability using a space relations test developed by Bennett, Seashore and Wesman (1991) focused on rotation and surface development rather than on visual penetration. Furthermore, in her study of pre-service elementary and middle school teachers, Black (2007) reported positive correlations between Earth Science conceptual understandings and spatial abilities and claimed that the Earth Sciences can be a useful vehicle for improving spatialisation abilities, in particular mental rotation. Unfortunately this work also did not specifically investigate VPA but found and confirmed that mental rotation ability is moderately correlated with success in Earth Science concept tests such as that developed by Libarkin Anderson, Boone, Beilfus and Dahl (2002). As Black (2007) has pointed out;

> *"… if a relationship exists between Earth science conceptual understanding and spatial ability, curricula may hopefully be developed to facilitate both spatial abilities necessary for Earth science conceptual understanding and understanding of spatially-related Earth science concepts that are associated with misconceptions and other broader conceptual problems". (p.4)*

For geographers and earth and environmental scientists, spatial literacy is a fundamental skill (King, 2006) but also one that presents many difficulties for students. An example of this is mentally moving between 2-D representations and 3-D (and especially 4-D for the geological sciences). Making a movie in the mind of 3-D changes to rock materials from origin to today (geological time) is an ultimate aim of geological thinking from measurable observations. Even in today's digital and visual world it is necessary to be able to spatially visualise a sense of location on a topographic map or a street map, and for geologists, making sense of 3-D depth from external observations of highly deformed strata on a 2-D sheet of paper takes considerable skill and training. Little wonder that current digital representations of

MRI, CT, ground penetrating radar, x-rays and sonar have opened our eyes to being able to ‘see inside’.

Research by Douglas and Bilkey (2007), indicates a strong linkage between people who are tone deaf and their ability to rotate 3-D cubic objects. This has led these researchers of neuropsychology to suggest that there are common brain processing mechanisms between hearing musical pitch and spatial ability: an area worthy of further research in the context of visually spatialising geological structures and strata deformation processes and consequences.

Although Mathewson (1999) took a ‘general science’ look at visual – spatial thinking and categorised types of visualisations commonly used in the Sciences, VPA *per se* was neither adequately categorised nor discussed. In Mathewson’s (1999) “master images of Science” (p.40), the closest VPA comes in his categorisation system is in “Gestalt”, a grouping which deals with figural closure, proximity, grouping, continuity, similarity and orientations. Mathewson points out the dominance of alphanumeric systems at the expense of visual – spatial thinking. VPA is a form of perceptual extension imaging and is closely related to Ekstrom, French, Hartman, & Dermen (1976) ideas of spatial relationships as the ability to manipulate an image into some other kind arrangement. Visual penetration requires the mental manipulation of surface stratification features that need to be mentally changed into ‘hidden continuations’ from the perception and visualisation of surface features, to the ‘inside’. It is unfortunate that Baldwin and Wallace-Hall’s tests of rotation (2004) given to high school and college age students, and using Ekstrom et al.’s validated tests of the 1960’s, does not address the issue of visual penetration ability.

Creative visualisation of concepts as an aid to explain natural phenomena is well established in the links between the ‘artist’ and the ‘scientist’ (Fazekas, 2004) but the ability to visually penetrate a geological structure is a skill that is uniquely required for the deciphering of historically distorted and confused rock strata. It rarely appears as a part of instructional and curriculum design for neither the sciences in general nor the geosciences in particular. Completing isometric drawings in a graphics class is not quite the same thing as visually penetrating a geological structure where issues of scale and connection with object identification and the real world are a necessity.

Learning a spatial sense is complexly experiential with many variables and it is difficult to measure (if not impossible) the contribution these different experiences have on learning processes. Piburn, Reynolds, Leedy, McAuliffe, Birk, and Johnson, (2002) in their study of spatial visualisation in the geological sciences indicate that ‘scientists’ score highly on spatialisation abilities and that the importance of spatial abilities in the sciences is “as important as verbal ability” (p.2). Indeed, high school and college age students apparently have higher scores on traditional measures of spatial ability than is true of other students of their age and ability (Carter, LaRussa & Bodner, 1987; Pallrand, 1984; Piburn, 1980).

2.9 Chapter Summary

This literature review discusses and synthesises the key conceptual issues surrounding the cornerstones of geological science education that is addressed in this thesis: geological time, scale and geospatialisation. The review shows how the seminal work of Piaget, Inhelder and Montangero on child development has been gradually built on by later researchers. These researchers are notably, Ault, Dodick, Libarkin, Manduca, Mogk, Orion, Trend and Tretter for geological time and scale with Black, Ishikawa Kali, Kastens, Libarkin, Orion, Piburn, and Reynolds for geospatialisation. These researchers have made a significant difference (especially in the sense of connecting neurocognitive science with geospatialisation skills) to our understanding of how students perceive and conceive their geological worlds. The challenge is for the educational community to find ways of including this research into school and college curricula and for geoscience education researchers to continue building on this base. As Kastens (2010) points out, object and spatial visualisation are the defining skills for interpreting geological phenomena and that geological science has the potential for developing and motivating individuals in both object and spatial visualisation abilities.

CHAPTER THREE

INTERNATIONAL GEOSCIENCE CURRICULA: A SELECTIVE OVERVIEW

3.1 Introduction

There are many geoscience/geology/earth science and science organisations but few dedicated specifically to international geoscience education. Recent developments from the education and cognitive science research section through the Carleton University website (http://serc.carleton.edu/) are welcome specific additions to the literature in geoscience education. As with all educational research dissemination and actioning of research findings at the classroom level for best practice are challenges yet to be realised.

The IUGS (International Union of Geological Sciences) is the largest Geological organisation in the world and has the affiliated Commission on Geoscience Education Training and Technology (COGE) responsible for supporting and encouraging the development of Geoscience educational issues. One stated objective of the IUGS is to *"assist the International Geoscience Education Organisation (IGEO) to undertake a world wide survey of the Earth Science perspective of school and outreach education"*. Aspects of results to this survey are discussed in this chapter. To meet this objective, the IGEO has in process for publication, the results of a 20 country response to a wide ranging questionnaire on the status of geoscience education. Results are to be eventually published in the IUGS journal *"Episodes"*.

The first conference for the fledgling IGEO occurred in 1993 at Southampton University. This organisation was inaugurated with a constitution at the second conference in Sydney in 2003, and is now affiliated to the International Union of Geological Sciences (IUGS). Southampton was the first international attempt to co-ordinate and discuss strategies for the enhancement of teaching and learning in the geological sciences in schools, tertiary institutions and institutions outside the main stream such as museums. This first conference also focussed on gathering 'global' data on the status of geoscience education in curricula and looked for a way forward in the teaching and learning of geological science. Information was formalised in the publication of conference proceedings (Stow, 1996). Further IGEO surveys were conducted on the status of geoscience education in 2002 and 2006 with a clear recognition of the low status of the geological sciences in curricula around the world and acknowledgement of the vitality of a geoscience literate society. The fourth international conference of IGEO in Calgary in 2003 further enhanced this view by using the theme of the conference *"Earth Science for the Global Community"*. Twenty five countries were represented at this conference. IGEO conferences are internationally unique specifically in the pursuit of geoscience education in the classroom and out of the classroom. An important conclusion reached was the recognition that there is a huge lack of information on specific Earth Science curricula from a wider range of countries despite efforts to gather data. This finding may not only reflect the values placed on Earth Science education in international science/geography curricula by educationalists (and politicians) but also the physical difficulty of gathering information. Different systems are difficult to rationalise and standardise. Interested and qualified people are needed to provide information. Nevertheless, as detailed in Chapter 1, the status and definition of Earth Science as a subject of teaching and learning in school curricula is precarious, undervalued and under resourced.

In essence, the IGEO grew from the key teacher training centre at Keele University (UK) and under the leadership of David Thompson from the early 1970's. It was my privilege to be with David for a short but influential visit in 1985. This centre was (and still is) one of the few teacher training institutions in the world to have established, well-resourced and dedicated courses in the teaching of geological science. Research in geoscience education spread from Keele to other centres such as the Weizmann Institute in Israel, University of Aviero in Portugal (Marques, 1997) and Ohio State University in the USA (Mayer, 1999).

This chapter focuses on the general status of the teaching of geological science from an international perspective based on a selection of countries and specifically addresses research question 1. Gaining valid, reliable and current information on more countries is extremely difficult and requires the resources of an internationally significant organisation with considerable resources and dedicated personnel. This information sets the scene for a detailed case study investigation of the status of Earth Science education and assessment in the national curriculum of New Zealand (See Chapter 9).

3.2 Earth Systems Science

The second IGEO conference was held in Hilo, Hawaii in 1997, and was themed by *Earth Systems Science,* a consequence of science education reforms (largely in response to political/social and environmentalist concerns and developed by NASA in the mid 1980's) from Ohio State University, and the trialling of Earth Systems Science for the teaching of geology in Japan. The future of Earth Systems Science remains to be seen. In Ian Clark's presidential address on a vision for Geoscience education for the 21st century at the 2006 IGEO conference in Bayreuth (Germany) (Hlawastsch, 2006), Earth System Science is seen as a way of teaching Earth Science as an integrating context for including science values, environmentalism and sustainability issues. However, Earth Systems Science appears to be somewhat at the expense of the traditional 'Earth materials', 'Earth structure', 'Earth resources' and 'Earth history' approach to a geoscience curricula. The relative absence of a coherent and standardised teaching of geological science in schools in Germany, for example, has led to the recent development of the "System Earth Project" (a project again derived from the evolution of the Earth Systems Science concept), in order to *"meet the requirements of interdisciplinary science and geography teaching". (Hlawatsch, et al. 2006. p.3).*

In a sense, curricula reforms encapsulate the socio/political issues of the time. For the early 21st century, 'climate change' is a key issue that dominates politics, economics and education and is reflected in the Earth Systems model of teaching science. King (2007) has provided a scheme to analyse the solid earth component of typical Earth Science courses including Earth Systems (See Table 3.1 and Chapter 9).

Nearly three decades later since ESS was promoted (Earth System Science Committee, 1988; Johnson, 2006), ESS has matured somewhat to become an important consideration and inclusion in science curriculum reforms such as in

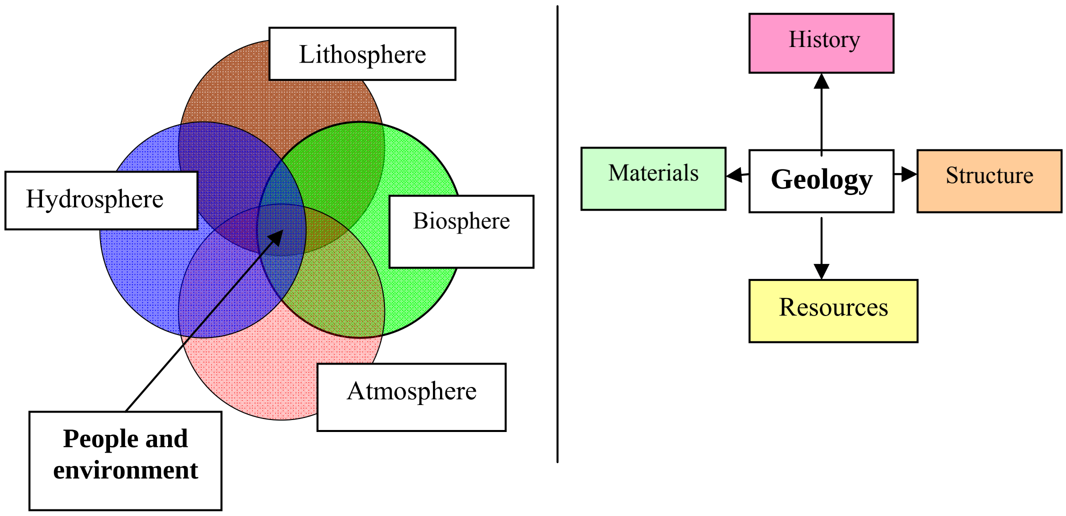
New Zealand (See Chapter 9) and in many other countries.

> *"Teaching and learning of Earth System Science in which state, process and understanding are represented as inseparable elements whether for breadth, depth or their combination is ideal for learning science in the classroom."* (Johnson (2006). p. 208). Well, perhaps?

Table 3.1. Comparison of *System Earth Project* content (Germany) with common Geological Science content.

German *System Earth Project* (After Hlawatsch & Bayreuber, 2006)	8 Element Content Scheme for Common Geological Science (After King, 2007, pers.com)
The rock cycle: documents of the Earth's history.	Geological time.
Origin and development of life.	Evolution of life.
None	Earth materials.
Convection in the atmosphere, hydrosphere and lithosphere.	Earth Energy.
System Earth – an introduction. *The Carbon Cycle.* *Climate and history of climate change.* *Chemistry and physics of the atmosphere.* *Plate tectonics and volcanism.*	Earth as interacting systems (environmentalism/sustainability)
None	Natural Hazards.
Resources and recycling. *The water cycle and the protection of drinking water.*	Earth resources and environment.
Earthquakes and wave energy. *Earth's interior.*	Investigating the Earth.

These *Earth System Project* topics (www.isb.bayern.de/isb/download.asp.) introduced into the German curriculum (Fachlerplan fuer Erdkunde) has built on the traditional discipline of geography to develop an integrated science framework for geoscience education across all levels of schools with a CD ROM made available. However, geological science is a vast discipline and cannot be easily fitted into already overcrowded curricula especially where there has been no tradition of having been so and remains limited in the *System Erde Project*. The ability to 'wedge' geological science into science curricula via environmentalism (as in the New South Wales (Australia) curriculum) is a significant barrier to improving the place and role of geological science in global curricula reforms. What do you put in and what do you leave out and why? What should students leave school knowing about geological science? As for teacher training in the geosciences, Lewis (2008) poses the question "How much college-level geoscience content is enough to provide a secondary teacher with a conceptual framework and a sense of the nature of geoscience"?



Earth Systems Science (ESS) (Interactive connections)

Traditional Geology (TG) (Analytical and reductive)

Figure 3.1. Comparison of Earth Systems Science with traditional Geology

These topics also reveal an important conceptual change in Geoscience (and Science) curriculum thinking from the earlier and traditional 'nuts and bolts' constructivist notions of Earth composition, structure and processes, to interacting 'systems' thinking with people and social issues at the centre. For the *Earth System Project*, studying geological time and history seems to be the trade off for the inclusion of environmentalism (http://www.systemerde.ipn.uni-kiel.de/materialien_Sek2_2.html). Germany rarely experiences volcanic eruptions, earthquakes and tsunamis which are common place on the Pacific rim.

Earth Systems Science demands considerable conceptual integration and an ability to perceive connections from diverse scientific disciplines. Indeed, this prerequisite ability indicates a crucial catch 22 aspect of learning about complex systems such as Earth systems. How can one understand system connections and interactions (e.g. between the biosphere and the Geosphere) without initial conceptual construction of system components before conceptualising system interactions? Conceptually, ESS curricula look at interrelationships of natural phenomena with people and environmentalism as the context, whereas traditional geology curricula focus on components. ESS reveals the current curriculum socialisation of Science as a subject of learning rather than just the 'Science'. It is also less constructivist than traditional courses in the sense that it focuses on system interactions rather than 'scaffolding' understanding of the scientific component concepts making up the systems.

When compared to a traditional geology curriculum such as the Pan Canadian Earth Science curriculum for grades 11-12 (age 16-18 years), the differences between an ESS philosophy and a constructivist ('bottom up' component) philosophy is clear. Traditional geology approaches include more on component knowledge such as the Earth's interior, rock and mineral classification and geological history rather than on interacting cycles and systems on which humans depend. ESS reflects the increased 'socialisation' values of Science curricula and addresses the common call to the question: 'how is Science useful to society'? It is the job of teachers to translate these knowledge expectations into manageable and meaningful chunks of learning that are pitched at the cognitive level of the average student.

Ben-Zvi-Assaraf and Orion (2005; 2009) have explored the many issues surrounding the conceptual development of student skills in systems thinking within the context of the water cycle. They found that there were two major factors influencing systems thinking skills development of students aged ten years:

> *(1) The students' individual cognitive abilities and (2) their level of involvement in the knowledge integration activities during their inquiry-based learning both indoors and outdoors* (Ben-Zvi & Orion, 2005, p.1).

How these two influencing factors vary with increasing age is a research question worthy of consideration. "Level of involvement" is likely to vary with motivation and intent. The ability to conceive and perceive interacting cycles within cycles and webs within webs requires a complex and high order systems thinking skill that develops with age. Kali et al. (2003b) in work related to student thinking about the rock cycle also indicate student cognitive limitations in ability to integrate system interactions. In the author's 36 years of teaching ecology to students aged 16 to 19, the inability to connect ecological systems appears to be a barrier to better understanding of ecological system interactions. Ben Zvi and Orion have categorised the characteristics of systems thinking and this is shown below. Systems' thinking has evolved from system dynamics and is essentially a learning construction of understanding the linking of webs and chains. However, systems' thinking has evolved from industrial systems dynamics and is essentially a learning construction of understanding the linking of webs and chains. However, in the Earth Sciences these webs and chains are complexly interwoven and require higher order thinking skills to make sense of geological phenomena and their interactions with other natural systems such as the biosphere. The cognitive difficulty for each of Ben – Zvi's and Orion's 'rock' cycle concept is based on the use of Bloom's taxonomy (Table 3.2) and rock cycle concept (Table 3.3).

Table 3.2. Typical characteristics of system thinking for rock cycle concept with cognitive difficulty based on Bloom's taxonomy (After Ben-Zvi & Orion, 2005).

Bloom's Taxonomic Descriptors	**Cognitive Level**
Analytic, Evaluative, Creative	Very High
Application	High
Explanation and comprehension	Medium
Descriptive and rote memory	Low

Table 3.3. The rock cycle concept and Bloom's taxonomy.

Ability of students to Identify:	**Rock Cycle example**	**Cognitive level**
Components	Igneous, metamorphic and sedimentary rock classes.	Low
Processes	Weathering, erosion, transport, deposition, melting, crystallisation, lithification, metamorphism.	Medium
Relationships	Transformation of rock classes	High
Organisation	Concept mapping	High
Generalisations	Rock cycle is dynamic and continuous	High
Hidden dimensions	Chemical and physical environments	Very High
Cyclicity	Geologic events and processes transform rock into different classes	Very High
Temporal thinking	Link with geological time and past geological events.	Very High

As shown in Table 3.3, the rock cycle concept as a system requires an understanding of the components and processes and how they work. Although these aspects constitute relatively low to medium level cognitive abilities, they are essential to enable a construction of system interactions. In short, the components and processes provide the knowledge base upon which everything else hangs. However, having knowledge of the components of this system is a first construction for many students which in itself, requires considerable literacy skills for 15 year olds despite being designated a low cognitive level. Explanatory knowledge of components is likely to be an important prerequisite for system interactions. Furthermore, it is likely that a sophisticated understanding of system interactions does mean sophisticated understanding of the components and process involved (Booth Sweeny, 2000). Table 3.4 identifies teaching and learning issues associated with geological time and a systems thinking approach.

Table 3.4. Typical characteristics of system thinking for geological time with cognitive difficulty based on Bloom's taxonomy (After Ben-Zvi & Orion, 2005).

Ability of students to Identify:	**Geological History**	**Cognitive level**
Components	Recognition of the fossil record, species identification, relative geologic time, absolute geologic time, correlation and Steno's principles of superposition.	Low to medium
Processes	Fossilisation, bedding structures, igneous intrusions, metamorphism.	Medium to high
Relationships	Cross cutting relationships and sequential geological events.	High
Organisation	Correlation diagrams. Mapping.	High
Generalisations	Understanding Earth's history	High
Hidden dimensions	Perception of time, measurement of 'deep time', plate tectonic mechanisms for change through time.	Very High
Cyclicity	Uniformitarianism and catastrophism.	Very High
Temporal thinking	Link with current geological processes.	Very High

Systems thinking also requires forward and backward thinking skills (positive and negative feedback loops) which enable linkage of complex components in interacting systems. Feedback loops require a very high cognitive level. Research by Gudovitch

(1997) and Kali et al. (2003) indicate that important learning steps (construction scaffolding) are needed for students to establish and construct adequate notions of system interactions and connections for understanding and application. Building a student's ability to 'bootstrap' their conceptual understandings of a scientific explanation of the world is an ultimate goal of science education.

The suggested learning steps of Gudovitch and Kali (1997) include:

1. Knowledge of the Geosphere, hydrosphere, biosphere and atmosphere Earth Systems.
2. Awareness of interactions between systems.
3. Knowledge and understanding of specific process mechanisms
4. Understanding of reciprocal component mechanisms
5. Overall systems perceptions.

It is hardly surprising that Kali et al. (2003) suggested that understanding and applying systems thinking are needed to 'solve' environmental issues in connection with earth systems, for example, requiring students to have a high cognitive level of operation. However, this is unlikely to happen with most students aged 13 to 18 years. In short, a student's ability to achieve meaningful connections between component interactions and between different systems, webs and chains is of a high thinking order that perhaps few high school students are able to achieve. Maybe this is why many high school biology students at age 16-18 years have difficulty fully understanding ecological interactions: teaching system interactions is not part of what is taught. This situation may severely limit the implementation of the goals of Earth Systems Science. However, Ben–Zvi and Orion (2005) suggest that high school students **are** able to cope with systems thinking, but how well, is determined by complex factors of cognitive barriers and teaching deliveries with established connections to fieldwork and learning outside the classroom (LEOTC), and also content-based teaching such as that promoted by Csapo (1999). Individuals understand different parts of system interactions with varying levels of success but teaching it is another issue and has constraint implications for teacher training and resources. Talking about 'systems' is one thing but teaching and understanding them in their scientific context is quite another. Mixing social science in terms of socio-scientific issues with 'science' is fraught with boundary difficulties (Sadler, 2004).

There is much research still to be done on investigating the cognitive and conceptual abilities of teenagers (and undergraduates) in their understandings of systems thinking and on investigating the place of Earth Systems Science in Science curricula and the ability of students to learn and apply systems thinking principles to Geoscience. As Sibley et al. (2007) point out in their exploration of the use of box diagrams to test student understanding and conceptual awareness of cyclic interactions within the water, carbon and rock cycles, students need to have knowledge of a systems 'jig–saw' components in order to understand or put together the whole picture. In other words, students often fail to perceive the transformative process connections that systems are constructed of and focus on the components without making the connections. Connecting the chains to the webs and then the systems is a difficult task for most students of University freshman and sophomore age (18 to 21 years). Box diagrams are essentially directing templates for students to demonstrate their understanding of system component connections. Also, using box diagrams may heave inherent bias (such as filling in a clockwise manner as reported by Sibley et al.) as well as students perhaps requiring prior training in using these boxes. Furthermore, expected connections would need to be 'customised' for different age of students as high school students are unlikely to be able to connect sophisticated chemical componentry to systems. The concept of a 'geological reservoir' may be beyond the cognitive ability of average 15 year olds. If, in Sibley et al.'s analysis, most students at age 18 to 21years focus on components, rather than processes, then students aged 15 are likely to struggle with knowing the basic components yet alone system process interactions interpretations and explanations.

Implementing well resourced ESS successfully in junior high school and high school (age 11 to 18 years) curricula may therefore demand too much of a cognitive leap and much research needs to be done to establish exactly what typical high school students of age 15 to 18 years are able to achieve.

According to Libarkin et al. (2006) ESS requires students to first understand the processes involved in a system such as in the rock cycle, and that this understanding is controlled by individuals' ontological points of view. The ontological categories (and cognitive abilities) held by students determines the degree of conceptual change (and hence system interactions) that students can achieve. This study by Libarkin et al. describes and confirms the cognitive and ontological barriers that need to be addressed if ESS is to be used for teaching geoscience and environmental interactions in a systems context. This was the original intention, as derived from NASA (1988) and Ireton et al. (1997) where 'Science' was taught in a systems context, and later developed for social/environmental/science values purposes (Mayer, 1995; 1997; Mayer, Fortner & Kumano 1999).

As Libarkin et al. (2005) point out, learning in ESS depends on students' being able to understand processes and that this is controlled by an individual's ontology. Sustainable change of ontological student views is **the** challenge of conceptual change. Ontological misconceptions compete with scientific conceptions for dominance. In particular, "constraint based interactions" (CBI) (Chi, 1994) is an ontological category relevant to systems thinking. For the geosciences, conceptual links that are ontologically fixed, between Libarkin's et al. (2005a) 'matter' or component (e.g. mineral properties) and 'process' or evolution of explanations (e.g. crystallisation) are crucial for understanding, for example, aspects of the rock cycle. The rock cycle is fundamental to lithosphere system interactions and, in turn, links to all other 'Earth systems'. Libarkin et al. (2005) used a hierarchical taxonomy of ontologies (Figure 3.2) to investigate student conceptions of fossils. In effect these authors found that this taxonomy requires considerable formalisation of cognitive abilities for students to grasp. Conceptualising systems is a complex matter. In any event, Libarkin et al. (2005) indicate that generally, undergraduate college-age students are conceptually at levels 1 and 2 (Figure 3.2). This implies that student ontological views need to be seriously addressed before specific topic teaching takes place.

> *Only one student out of the 61 interviewed for this study was found to sit at a Process level ontologically, indicating that students may not be ready for ESS instruction at the start of an introductory course. (*Libarkin et al. 2006, p.6)

For younger students aged 13 to 15 years, many are likely to be at ontological level 1 and these students in particular are likely to benefit from geological fieldwork with specific and well-structured topic instruction. Building on the work of others (Orion 1993; Orion & Hofstein 1994; McLoughlin, (2004)), Elkins & Elkins (2007) showed that field-based courses also positively influenced geoscience concept learning for first year university geology students. Once beyond the 'novelty of the learning environment' (socially and physically), students improve their connectivity with geological concepts. There is little doubt that social and place novelty along with contact hours in the field are significant (and testable) variables in achieving understanding of geoscience concepts such as stratigraphy and geological structures. However, the challenge is to plan and prepare well-connected field experiences for specific geological phenomena. Here, the selective use of Libarkin and Anderson's Geoscience Concept Inventory (GCI) is a useful conceptual 'pre-test' starting point in measuring changes in geoscience conceptual understanding as a result of field-based experiences.

Level 5 (high)	**Level 4** ←	**Level 3**	**Level 2**	**Level 1 (Low)**
Systems				
	Full Processing			
		Partially Explanatory		
			Transformative Mechanisms	
				Material (Components)

Figure 3.2. A hierarchical taxonomy of ontologies (After Libarkin et al., 2005)

Learning geology from fieldwork is more likely to be successful when students actually do the 'dip and strike' measurements or 'dig the fossils out' or collect rock samples and make the conceptual connections for themselves (from clear objectives), rather than by being shown, lectured and asked impossible questions at outcrops from a bus window in a howling wind. Making scalar connection with the 'real world' may be the key factor in developing geological skills.

Briefly, in England and Wales, there has always been a tension between geography as the 'home' of the geological sciences, with topics including earthquakes and plate tectonics, and Science, with topics such as rocks, minerals, weathering and the rock cycle. Geography 'socialises' geological science in the sense that easily observed surface features and how people interact with these features becomes a focal point. The main tension between geography and Earth Science as vehicles for teaching solid earth, geological science is the focus on social aspects in geography rather than the scientific aspects. In England, recent curriculum reforms for key stage 4 for 14 to 16 year olds (King, pers. com.) suggest that a new course in Earth and Environmental Science may be a way of including geological science as an integrator for environmental science in a similar way that ESS has been developed. It is also suggested that environmental science is within a geological time and biological context. This is a similar approach to the Australian Earth Science curriculum reforms of 1997 to 2002 (Hafner, 2003) after the collapse of geological science in the Australian science curriculum and represents a variant of ESS thinking. Australian earth and environmental science courses are available for students aged 16 to 18 years with contributing earlier courses delivered via the Science programme. The Years 7-10 geological science contains the same topic content as the stage 6 higher school certificate course in New South Wales.

The development of the Australian Earth and Environmental Science course for senior high school students is an attempt to integrate geological science with systems and cyclic thinking within an environmental context. Understanding the environment and how people interact within it is the main reason for studying geological phenomena rather than investigating the science of geology per se. A rationale for Earth and Environmental Science has been provided by the New South Wales Board of Studies and is quoted below.

> *"Earth and Environmental Science in Stage 6 Science is the study of the Earth and its processes. The course aims to provide an understanding of systems and processes in both aquatic and terrestrial environments. It seeks to explore changes that have occurred during Earth's history, including changes in the lithosphere, atmosphere, hydrosphere, cryosphere and biosphere, and the evolution of organisms since the origin of life on Earth.*

> *"The study of planet Earth and its environments recognises that while humans are part of nature they continue to have a greater influence on the environment than any other species. Earth and Environmental Science is built on the premise that the natural environment is the host to all local environments and that, therefore, an understanding of the natural environment is fundamental to any analysis of more specific local environments"*. (Earth and Environmental Studies, Board of Studies, New South Wales, Australia. p. 6)

Table 3.5 summarises the essential content of the Australian Earth and Environmental Science course within the framework used by King (2007) for geological science (geology) content that is common in geological science courses throughout the world (Given the current state of knowledge). In this scheme, King (2007) acknowledges the difficulty and debateability of assigning content knowledge and concepts to a generalised scheme. However, the intent of this scheme is to find overall patterns and connections for curriculum content inclusion of essential solid earth geological science concepts within the frameworks of different countries science curricula. The elements which make up this "8 element common content scheme" are also shown in Table 2.5.

For New South Wales in Australia, the Earth and Environmental Higher School Certificate course (HSC) requires 240 hours of tuition (New South Wales Board of Studies, 2002) over a two year period. There are three core modules and one of four options, so it is still possible for many students to miss out on key aspects of geological science such as 'geological time', the fossil record and evolution. The Earth and Environmental Science course appears to be structured for students entering the workplace as well as for those wishing to further their studies (See page 7 of the stage 6 New South Wales syllabus).

Table 3.5. A selected analysis of the Australian (NSW) Earth and Environmental Science curriculum and Geology

2007 Australian Earth and Environmental Science (Stage 6, HSC, ages 16-18)	**'8 Element Common Content Scheme' for Geological Science** (After King, 2007)
** The evidence provided by geological records suggests that there have been climatic variations over Earth's history.* ** Outline the main stages involved in the growth of the Australian continent over geological time as a result of plate tectonic processes.* ** Identify that geological time is divided into eons on the basis of fossil evidence of different life forms.* ** Gather and analyse information from a geological time scale and secondary sources to identify and date the major evolutionary advances made by plants and animals.* ** Gather information from secondary sources and use available evidence to identify the relationship between mass extinctions and the divisions of the geological time scale*	Geological Time
** Compare uses of relative and absolute dating methods in determining sequences in the evolution of life forms.* ** The Cambrian event.*	Evolution of life
** Describe the relationship between the density of Earth materials and the layered structure of the Earth.* ** Define fossil fuels as 'useful organic-matter-derived Earth materials'*	Earth materials
** The properties of economically important Earth materials formed from organic material (fossil fuels).* ** The search for alternative sources of fuels.* ** Describe the four types of mass motions of water: surface currents, deep circulation, tides, tsunamis, and identify the energy source for each.*	Earth Energy
** Interacting subsystems of the Earth that together produce a unique biome.* ** The course aims to provide an understanding of systems and processes in both aquatic and terrestrial environments.*	Earth as a System
** Natural disasters are often associated with tectonic activity and environmental conditions caused by this activity may contribute to the problems experienced by people.*	Natural Hazards
** Identifies the origins of Earth's resources evaluates the use of the Earth's resource describes and locates available resources in* ** Australian environments and evaluates the impact of resource utilisation on the Australian environment. Australian resources and biotic impacts on the environment.*	Resources and Environment
** P2 applies the processes that are used to test and validate models, theories and laws of science with particular emphasis on first-hand investigations in Earth and Environmental Science.*	Investigating the Earth

It seems then that although the New South Wales experience of developing Earth Science curriculum for senior high school students is cognisant of systems thinking, this is not the primary reason for studying geological science. There is a broad coverage of geological science principles and content and there is importantly, coverage of geological time and evolution within the geological context, but the curriculum is also clearly related to the New South Wales environment and the impact of humans upon this environment. The Australian curriculum has a preliminary course (containing prerequisite content from earlier years, ages 13-15 years), and the HSC. The assessment tasks for this curriculum, like New Zealand to some extent, are based on Bloom's taxonomy of cognitive ability and are non-ranking.

It is noteworthy that ESS and recently reformed Science curricula (e.g. in New Zealand) attempt to increase the 'socialisation' of Science by reference to human interaction with the environment. Indeed, modern catchwords are 'social sustainability', 'numeracy', literacy', climate change' and 'environmental'. Does this represent a politicisation of curricula or educational advancement? With the inclusion of environmentalism as a focal point in ESS, the 'Science' necessarily (arguably) becomes diluted and indicates an example of the way in which curricula become overcrowded. It is unfortunate that altering curricula is unlikely to change student conceptual ontologies about science. However, this is a question worth investigating. Sustainable and scientifically meaningful conceptual change is clearly more complicated than altering a single variable! Geological science does not have its own place in the curriculum for England and Wales. All students between the ages of 5 and 16 years in England and Wales are required to follow a national curriculum.

3.3 An Evolving 'Traditional' Geology Approach: The Canadian Experience

When the Canadian Earth Science curriculum for senior high school students is investigated within the same 'common content of geological science scheme' (after King, 2007), it is clear (and disappointing) that along with natural hazards, the two key concepts of geological time and evolution of life are absent. Table 3.6 summarises the key elements of the Canadian high school Earth Science content.

Table 3.6. The pan-Canadian Grades 11-12 **Earth Science knowledge** requirements (www.cmec.ca/science/framework/)

Pan Canadian Earth Science (Grades 11-12 , ages 16-18)	**'8 Element Common Content Scheme' for Geological Science** (After King, 2007, pers.com)
None	Geological time
None	Evolution of life
330-2. Classify rocks according to their structure, chemical composition and method of formation	Earth materials
332-1. Analyse energy and matter transfer in the water cycle.	Earth Energy
330-5. Describe the composition and structure of the atmosphere. *330-6. Describe the dominant factors that produce seasonal weather phenomena.* *332-1. Describe interactions of components of the hydrosphere, including the cryosphere.* *332-3. Describe major interactions among the hydrosphere, lithosphere, and atmosphere.*	Earth as a System
None	Natural Hazards
330-4. Analyse the interactions between the atmosphere and human activities.	Resources and Environment
330-1. Describe theories and evaluate the limits of our understanding of Earth's internal structure.	Investigating the Earth

The Canadian curriculum indicates a mixture of 'traditional' geology content (Earth's interior and rock classification), with aspects of 'modernist' Earth systems science in the form of describing interactions between the hydrosphere (Ocean) lithosphere (Rocks) and the atmosphere (Gas). Like the Australian curriculum, the senior content is built on similar content taught at the junior level. As with many 'revised' geoscience curricula, Earth Systems concepts are clearly enunciated and indeed form a significant part of ensuring geological concepts are delivered in a curriculum through integration with environmentalism. For a high latitude country like Canada, understanding the 'cryosphere' as continental ice sheets is important and illustrates the importance of local natural environments to people.

3.4 International Comparisons

In an attempt to find general similarities in the geology content included in different countries Earth Science curricula, multivariance cluster analysis (Kovach, 2003) was performed for country wide data displayed in Table 3.7 and expressed as a dendrogram (Figure 3.3).

Table 3.7. Inclusion of the '8 Geological Science Commonalities' as represented in different countries Earth Science curricula (IGEO 2002 database)

'8 Element Common Content Scheme' for Geological Science (After King, 2007)	**USA**	**Scotland**	**Taiwan**	**Japan**	**South Korea**	**New Zealand**	**Israel**	**Australia**	**South Africa**	**Canada (age 16-18)**	**Germany**	**England**	Mode
Geol. Time	1	0	1	1	0	0	0	2	0	0	0	0	0
Evolution	1	1	1	2	1	0	1	1	1	0	0	1	1
Energy	1	1	1	2	3	2	1	1	1	1	1	1	1
Materials	1	1	1	1	1	0	1	1	1	1	1	1	1
Systems	1	1	0	1	1	1	1	1	0	1	1	1	1
Hazards	3	1	1	1	1	1	1	2	0	0	0	1	1
Resources	3	1	1	1	1	0	0	1	1	1	0	1	1
Investigation	3	1	1	2	1	0	0	1	1	1	0	1	1

Key: None = 0 Yes = 1 Partial = 2 Unknown = 3

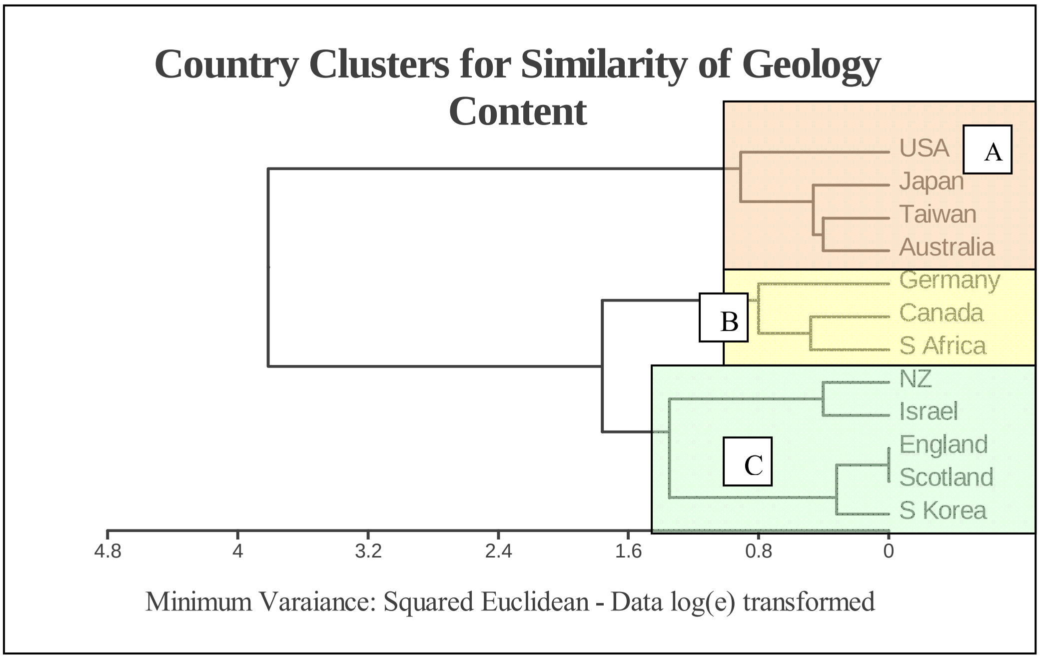


Figure 3.3. Country cluster dendrogram analysis for Table 2.7.

As shown in Figure 3.3, there are three clusters of countries **with similar geological science content** inclusion in their Earth Science curricula. Geological content is based on King's (2007) generalised "8 geology scheme" for geological content for each country's Earth Science curriculum. These clusters are shaded. The geological content included in Earth Science curricula is shown in Table 2.7. Country cluster C appears to be subdivided into two smaller clusters of equal similarity in terms of geology content inclusion. Cluster B would indicate that although Germany is in this cluster the geology content is a little different. Differences are likely to be reflected in each country's focus or emphasis on particular geological aspects that are unique to them. For example, in Germany there are few active geological (solid earth) hazards such as earthquakes and active volcanism so this is not included in Earth Science curricula.

Figure 3.4 presents a dendrogram again derived from King (2007), but clusters the **percentage of statements relating to 'geology'** as the solid earth component within Science curricula for each country. The challenge is to increase the data available for more countries.

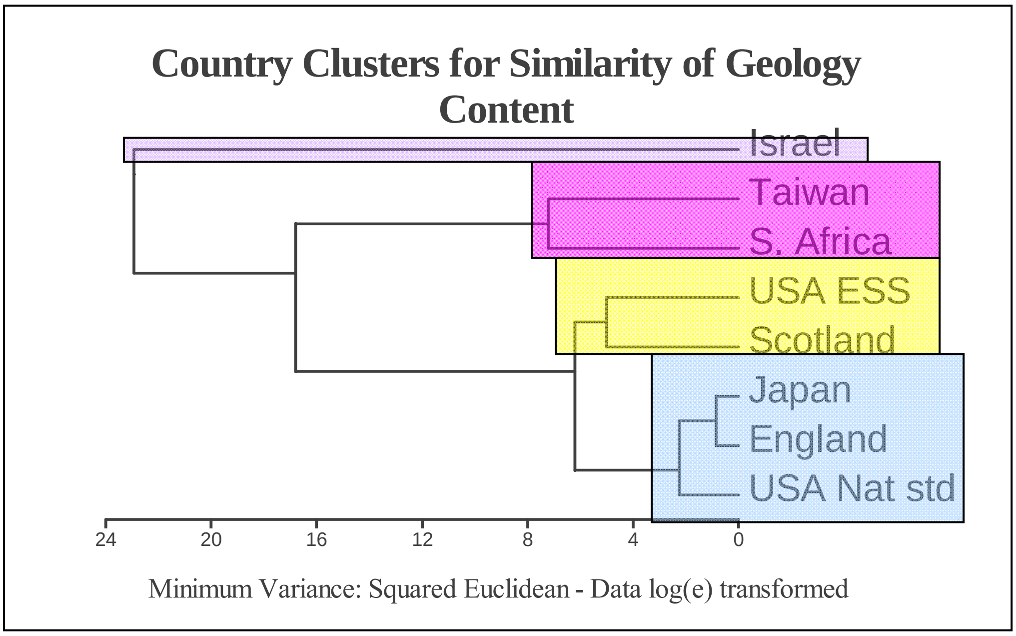


Figure 3.4. Cluster analysis of percentages of statements about Geology in different countries Science curricula. (Data derived from King, 2007).

An interpretation of the dendrogram in Figure 3.4 would suggest that of the four country clusters, Israel is separated by its emphasis on topics such as systems, materials and evolution of life. This is a significantly different geology content emphasis to other countries (See Table 3.7). Indeed, 77% of geology statements in the Israeli curriculum are focused on systems and materials. It is clear that the inclusion of the American-lead ESS in particular, since the mid 1990's on Earth Science curricula, has been significant with the Israeli curriculum registering four times the percentage of statements in their science curriculum than that of the USA national standard statements and two times that of the Earth Systems Science curriculum. A key element of the Israeli curriculum is about teaching the understanding of system interactions and environmentalism in a country dependent on water for survival. Teaching systems such as the water cycle and the rock cycle not only enables more efficient means of teaching concepts involved in the nature of science (Orion, 2005) but also enables learning of key geological processes and phenomena.

Table 3.8 Percentage of statements in Science curricula relating to geological science components (After King, (2007)

Geology Components	Country									
	New Zealand	USA ESS	USA Nat'l Std's	Israel	Japan	Scotland	S. Africa	Taiwan	Suggested for England	**Average**
Materials	**4**	10	10	33	26	25	23	18	23	19%
Resources	**0**	17	29	0	17	8	23	36	13	18%
Systems	**67**	21	10	44	9	33	0	0	17	22%
Investigation	**33**	34	5	0	13	8	15	3	23	15%
Energy	**25**	7	5	0	9	8	38	18	3	13%
Evolution	**0**	7	19	11	9	8	8	3	7	9%
Hazards	**17**	0	14	11	9	8	0	18	7	9%
Geol. Time	**0**	3	10	0	9	0	0	3	7	4%

Of 'traditional' geological content, earth materials and resources remain the most important, together making up an average of 39% of curriculum statements in Earth Science. Although the national US standards are reasonably well balanced for content, the standards remain a recommendation for curricula rather than actual. As might be expected from an economic point of view, the South African curriculum focuses on materials, resources and energy. Energy issues are by far the most important not only within the curriculum but also across country curricula. Similar 'economic' arguments can be advanced for Taiwan, where the focus is on resources, hazards and materials. It is important to point out that the "8 element scheme" used for analysis does not specifically include aspects such as geological structures and spatialisation, but are implicated in topics such as geological hazards and materials. The inclusion and growth of 'Earth Systems' into curricula since the mid 1990's is significant with New Zealand's 2010 revised curriculum being of particular note.

From the author's perspective, the most disappointing aspect of this analysis is the diminution of the single most important topic that geology brings to a scientific literacy: geological time. It remains the least mentioned topic in curricula yet is educationally significant for all sciences. As mentioned elsewhere, nothing in the Sciences makes a lot of sense without the framework of geological time. The low status of geological time as an aspect of earth science is illustrated in Figure 3.5 dendrogram, where clustering analysis was performed for 13 countries. A similar analysis was carried out for King's data on seven countries and is shown in Figure 3.6.

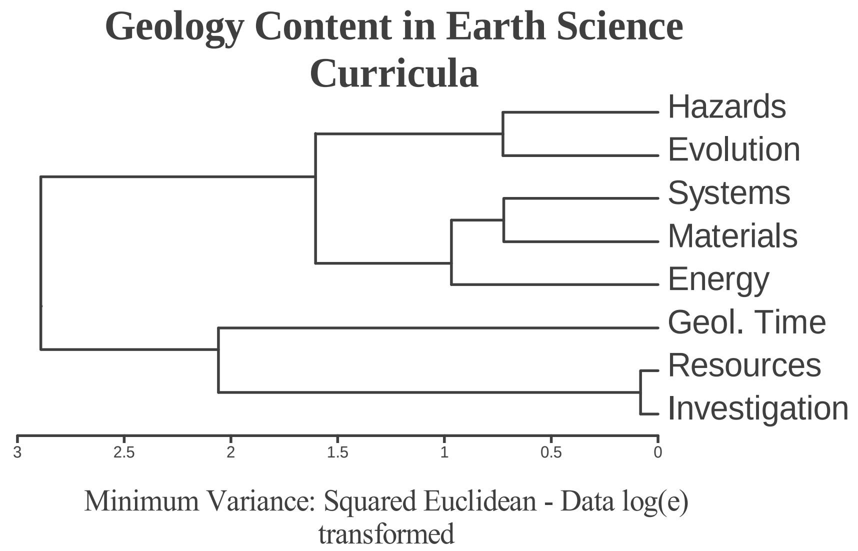


Figure 3.5. Geology: content clusters for Table 3.8

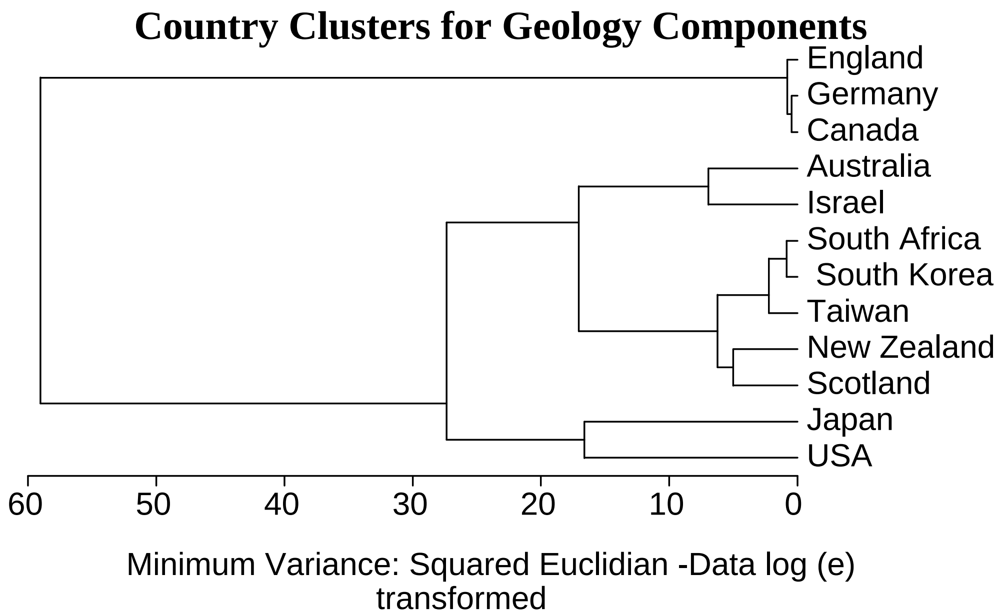


Figure 3.6 Geology: country clusters for Table 3.8

Both dendrograms illustrate the low status of geological time as a topic for Earth Science curricula. However, for King's data, geological time is clustered with geological hazards, both of which are closely related by making up the least mentioned topics in curricula statements in King's database.

3.5 The 2002 IGEO International Survey: Summary

A précised selection of key school and university Earth Science research questions from the 2002 IGEO survey are shown in Figure 3.7 (Dowse, 2004). Although US-oriented, the questions are designed (with varying interpretation problems) for an international audience to gain some insight into the status of geoscience education at a global level. Solutions for difficulties in geoscience education can come only after information gathering.

A SCIENCE EDUCATION STANDARDS

1. *Does your country have defined national Earth science education standards?*
2. *Do local school districts or other political subdivisions have defined earth science education standards of learning?*
3. *Are there system deficiencies that make the implementation of established science standards difficult or impossible? (For example, lack of teacher training or qualifications, lack of funds to support development of materials and purchase of supplies, lack of qualified teacher trainers, some level of system disinterest, etc.)*
4. *Are there local, regional or national tests, which provide baseline information on student learning in the Earth sciences? If so, are these tests required and how are the resulting test data used? If there are many varieties of local, regional or national tests, give an overview of these tests rather than a test-by-test evaluation.*

B PROGNOSIS FOR THE FUTURE:

1. *What do you see as the major problems facing geoscience education in your country?*
2. *What changes do you expect to see in the next three years?*
3. *What specific support could the global geoscience community provide to facilitate geoscience education in your country?*

Figure 3.7. Selected 2002 IGEO survey questions

3.6 Are There National Standards? A Discussion

Although a relatively small dataset (16 countries), the sample is from a diverse range in terms of culture, socio-economics and educational history. However, in essence, European colonialism of the late eighteenth and early nineteenth century has left its mark and remains the most powerful influence on many school curricula. In particular British colonial attitudes towards education appear to have had an important influence, often to the extent, that in New Zealand for example, examination papers were written in England and student papers were sent to and marked in England up until the 1930's (Grant, 2003). It is only in recent times that much more attention has being given to first nation values for inclusive enrichment of curricula (Freeman, 2007; Riggs, 2004; Riggs, 2003; Semken, 2007). In essence, research by these authors confirms the fundamental importance of people's cultural connections to the land (place-based concepts) and points the way to the development of meaningful learning of geological science concepts to the land that is likely to be hard-wired into the brain. As Freeman (2007, p.1) points out, *"Place – based teaching methods in geoscience merit further study at the undergraduate and graduate level"*. The power of placed–based learning is constructed learning connection between culture, history and traditions within a modern geoscience process context. In New Zealand, the indigenous Māori population has finely tuned religious, political, social and cultural connections to the land and learning rewards may be achieved through developing a curriculum for school students around this concept. Understanding placed–based cultural and physical environmental roots can be a powerful motivator to make sense of a scientific geological history in a modern cultural context.

So, are there national standards for geoscience education across different countries? Table 3.9 indicates that the answer is a qualified yes (often depending on the implemented definition of 'standard'), with 69% of this sample in the affirmative. Standards may define the curriculum but in some countries such as New Zealand, 'standards' are also used as national assessment standards and are derived from national curriculum statements. This situation generates a tension between standards as statements of subject-content intent and statements of curriculum for national assessment qualifications. New Zealand curriculum statements are framed as achievement aims and achievement objectives with specific learning objectives (SLO's) the equivalent of a 'syllabus'. However, in the 2007 reviewed curriculum, SLO's are not defined and are left to teachers to construct. This is an area of political division and concern. It is unfortunate that in the IGEO survey of 2002 (and 2006), 'standards' are not defined (Dowse, 2002). However, in large state-wide countries such as the USA and Australia, standards are not compulsory because compulsion may be perceived to be counter to state wishes and a threat to state control and autonomy. As a consequence, standards appear to be strong recommendations for educational ideals and consistencies rather than directives. Having national standards available does not necessarily mean they are implemented. Smaller countries such as New Zealand, Wales, Scotland and Israel could be considered city states, and as such, it makes sense for these countries to have national (and manageable) curriculum standards for teaching, learning and assessment.

Table 3.9. Question A.1. Summary: Are there national Earth Science standards?

Country	**Yes**	**No**	**Response Summary**
Argentina	Y		Details not provided
Australia	Y		Assessment is state controlled.
Bangladesh	Y		Specific ES curricula but mostly part of geography.
Brazil		N	No specific ES curricula but part of natural sciences and geography
Canada		N	Education is a provincial responsibility
Indonesia		N	Partially. Have national standards in 'geographical science'.
Israel	Y		But not phrased in a 'standards form'. Specific to elementary, junior high & high school.
South Korea	Y		For all elementary and secondary schools.
Mozambique		N	Earth Science syllabus not included in curricula at any level. Geography dominates.
New Zealand	Y		As part of the national science curriculum years 1-13 and assessed by standard criteria from age 15 to 19.
Norway	Y		For grades 1, 5 and 8.
Philippines	Y		As part of the Science learning Competencies.
South Africa		N	1996 revisions never implemented. 2000 revisions placed ES in geography.
Taiwan (ROC)	Y		ES standards specifically for grades 9 and 10.
UK/.Wales	Y		Limited 7% ES 11-16 year olds. PhysICAL geography a key element.
USA	Y		Nat Science Standards adopted in 1996 but not compulsory.
% (N =16)	69	31	

3.7 U.S.A. and New Zealand Geoscience Curricula: A comparison

New Zealand and the U.S.A are hugely different in demography and culture, but share some common ancestry in educational evolution. Both countries derive a western educational philosophy from a variable but essentially British colonial origin and in the US in particular (Ireton, 2003), the National Education Associations (NEA) Committee of Ten recommendations in 1894 introduced Science into schools with geoscience (as in NZ), in the form of physical geography.

Tables 3.10 and 3.11 compare the New Zealand revised and gazetted (November, 2007) Geoscience curriculum and the USA national standards for equivalent student age groups (US grades 9-12 and NZ Years 9-13 = age 14 to 18 years). The commonalities in concept/content are recorded in red. A quick word search indicates that in the US standards there is an emphasis on energy and atmosphere. Perhaps this reflects a continents' preoccupation with maintenance of status and the need for energy to fuel an economy as well as a perceived educational need to relate the extraction and use of energy with its impact on major issues such as global climate change? The New Zealand geoscience curriculum focuses on Earth systems in terms of composition, structure, process, natural hazards and human activities. Investigation of "interacting systems" focuses on heat distribution and the cycling of carbon. To be clear, the November 2007 New Zealand curriculum is to be fully implemented into classrooms in 2010 and this will include updated and aligned assessment standards of which the geoscience strand will involve the greatest change (See Chapter 9 for a detailed postscript on science curriculum reforms). The current 1994 New Zealand curriculum and assessment standards will remain in place until 2011 and a major pedagogic challenge awaits the implementation of "how to teach the complex chemical, geological and biological systems interactions for NZ Year 11, 15 year old students.

Table 3.10. The New Zealand Geoscience curriculum content (Ministry of Education, 2007 - 2010).

CL	Earth Systems	Interacting Systems	Astronomy
L5 **Age 13/14**	Investigate the composition, structure, and features of the geosphere, hydrosphere, and atmosphere.	Investigate how heat from the Sun, the Earth, and human activities is distributed around Earth by the geosphere, hydrosphere, and atmosphere	Investigate the conditions on the planets and their moons, and the factors affecting them
L6 **Age 15/16**	*Investigate the external and internal processes* that shape and change the surface features of New Zealand.	Develop an understanding of how the geosphere, hydrosphere, atmosphere, and biosphere interact to **cycle carbon** around Earth.	Investigate the interactions between the solar, lunar, and Earth cycles and the effect of these on Earth.
L7 **Age 16/17**	Develop an understanding of the causes of natural hazards and their interactions with human activity on Earth.		Explain the nature and life cycles of different types of stars in terms of energy changes and time.
L8 **Age 17/18**	Develop an in-depth understanding of the interrelationship between human activities and the geosphere, hydrosphere, atmosphere, and biosphere over time.		Explore recent astronomical events or discoveries, showing understanding of the concepts of distance and time.

Note: CL = Curriculum level. .AO = Achievement Objective. Red = common curriculum content intent with US curriculum standards.

Table 3.11. The United States **national** Geoscience curriculum content standards

Concept	Content for grades 9-12
Energy in the Earth System **(Red = common to NZ curriculum intent at age 13/14)**	Earth systems have internal and external sources of energy, both of which create heat. The sun is the major external source of energy. Two primary sources of internal energy are the decay of radioactive isotopes and the gravitational energy from the earth's original formation. The outward transfer of earth's internal heat drives convection circulation in the mantle that propels the plates comprising earth's surface across the face of the globe. Heating of earth's surface and atmosphere by the sun drives convection within the atmosphere and oceans, producing winds and ocean currents. Global climate is determined by energy transfer from the sun at and near the earth's surface. This energy transfer is influenced by dynamic processes such as cloud cover and the earth's rotation, and static conditions such as the position of mountain ranges and oceans
Geochemical Cycles **(Red = common to NZ curriculum intent at age 15/16)**	The earth is a system containing essentially a fixed amount of each stable chemical atom or element. Each element can exist in several different chemical reservoirs. Each element on earth moves among reservoirs in the solid earth, oceans, atmosphere, and organisms as part of geochemical cycles. Movement of matter between reservoirs is driven by the earth's internal and external sources of energy. These movements are often accompanied by a change in the physical and chemical properties of the matter. **Carbon**, for example, occurs in carbonate rocks such as limestone, in the atmosphere as carbon dioxide gas, in water as dissolved carbon dioxide, and in all organisms as complex molecules that control the chemistry of life.
Origin and Evolution of the Earth System **(Red = common to NZ curriculum intent at age 15/16)**	The sun, the earth, and the rest of the solar system formed from a nebular cloud of dust and gas 4.6 billion years ago. The early earth was very different from the planet we live on today. Geologic time can be estimated by observing rock sequences and using fossils to correlate the sequences at various locations. Current methods include using the known decay rates of radioactive isotopes present in rocks to measure the time since the rock was formed. Interactions among the solid earth, the oceans, the atmosphere, and organisms have resulted in the ongoing evolution of the earth system. We can observe some changes such as earthquakes and volcanic eruptions on a human time scale, but many processes such as mountain building and plate movements take place over hundreds of millions of years. Evidence for one-celled forms of life--the bacteria--extends back more than 3.5 billion years. The evolution of life caused dramatic changes in the composition of the earth's atmosphere, which did not originally contain oxygen.
Origin and Evolution of the Universe	The origin of the universe remains one of the greatest questions in science. The "big bang" theory places the origin between 10 and 20 billion years ago, when the universe began in a hot dense state; according to this theory, the universe has been expanding ever since. Early in the history of the universe, matter, primarily the light atoms hydrogen and helium, clumped together by gravitational attraction to form countless trillions of stars. Billions of galaxies, each of which is a gravitationally bound cluster of billions of stars, now form most of the visible mass in the universe. Stars produce energy from nuclear reactions, primarily the fusion of hydrogen to form helium. These and other processes in stars have led to the formation of all the other elements.

The key difference between these two national curriculum standards **(for student ages 13 to 18 years)** is that the 2007 NZ geoscience curriculum aims and objectives do not overtly recognise the significance of geological time, the fossil record, stratigraphy, and geological histories, and in particular, the connection of the geosphere with the biosphere in terms of biological evolution. In a curious sense, the defining elements of geological science (Geological time, stratigraphy, history and the fossil record) are commonly reduced or absent in many other curricula as well (See Table 3.9). The 'unpicking' of the NZ curriculum to define the intended direction of the aims and objectives will have to wait until around 2010 before being implemented into schools. It is interesting that the NZ 1969 Science syllabus clearly recognised the importance of fossils as evidence of evolution, geological history and geological processes (Department of Education., 1968).

Level 8 (Year 13) of the NZ Science curriculum recognises aspects of 'time' for earth's systems, but very few students (and schools) actually end up learning this material (See Chapter 9 for details). The U.S.A. standards carry a degree of 'unpicking' and clearly indicate the importance of earth history, the evolution of life and measurement of geological time. The NZ curriculum leads from general composition, structure and features of the geosphere, atmosphere and hydrosphere at ages 13-14 years to processes controlling surface features at age 15 and then to looking at causes of natural hazards and human interactions over time. This leaves little room for investigating the fossil record, geological history and geological processes in a combined tuition time of around eighty to hundred hours in three years. The emphasis is on interacting systems.

It is indeed an educational concern that the single most important contribution that the geological sciences make to a scientific understanding of the Earth (Geological time and history through stratigraphy and the fossil record) does not have a presence in the 2007 level 1 *Planet Earth* strand of the NZ national Science curriculum. This **was** recognised in the 1994 geoscience curriculum (See Chapter 9). The absence of conceptual development of geological time and the fossil record in the NZ curriculum inevitably impacts on a student's conceptualisation of the origin and evolution of life when studied in the biological sciences (Living World strand).

A significant problem with the national USA geoscience standards is achieving consistent national implementation in an autonomous state wide federation, rather than absence of the key elements of geological science. Measuring geological time, biostratigraphic correlation and geological history is clearly indicated in the U.S.A curriculum but not in the NZ curriculum. It is also unfortunate that King (2007) does not clearly acknowledge and include the key geological elements of biostratigraphic correlation, geological history and the fossil record in other country's geoscience curricula: the "eight elements" do not clearly cover these aspects. To reiterate, this comparison is relevant only to students aged 13 to 18 years largely because these are the years in which 'high stakes' national or state wide qualifications become important to future student learning and careers. For the NZ curriculum, preparing assessment standards (and tasks/exams) that are derived from the revised 2007 curriculum may provide a considerable pedagogical challenge. At curriculum level 6 for example, exactly what are student's expected to know and understand about system interactions for cycling carbon? There is a lack of research here.

The astronomy section of the NZ curriculum fares little better than the geological science section in comparison to the U.S.A. curriculum. It is intriguing that the NZ 'astronomy' objectives do not include the origin and evolution of the universe but focus instead on the nature of stars, features of planets and moons, spatial relationships and astronomical events and discoveries. Indeed, the NZ astronomy section at all levels makes no mention of a scientific understanding of the origin and evolution of the universe.

3.8 International Geoscience Curricula Prognosis

Respondent perceptions that are considered to be significant barriers to the development of geoscience content curricula (Dowse, 2002) are summarised in Table 2.12.

Table 3.12. Summary - Barriers to establishing Earth Science standards

Country	Response Summary
Argentina	Lack of trained and qualified teachers. Lack of resources. Insufficient time.
Australia	Lack of trained and qualified teachers. Little money for upgrading qualifications.
Bangladesh	Lack of money. Lack of trained and qualified teachers.
Brazil	Low status and lack of Earth Science in curricula. Poor standard of students entering University.
Canada	Lack of training. Little institutional support in junior and secondary schools.
Indonesia	Overcrowded curricula. Lack of trained teachers. Lack of money. Lack of resources.
Israel	Reluctance of teachers to make changes.
Japan	Lack of money. Lack of resources. Systemic changes needed. ES now elective and integrated.
Korea	Fear that the number of students (schools) offering ES will decrease.
Mozambique	Lack of trained and qualified teachers. Out of date syllabus. Lack of money and resources
New Zealand	Lack of trained and qualified teachers, resources. Low historical status of ES in curriculum.
Norway	Lack of qualified teachers.
Philippines	Lack of trained and qualified teachers. Out of date resources.
South Africa	Lack of trained and qualified teachers, resources and money.
UK/Wales	Lack of trained and qualified teachers. Poor resources. Negative teacher attitudes.
USA	No response, but likely to be state socio/political barriers such as that involved with the teaching of the fossil record, geological time and biological evolution.

As presented in Table 3.12, the major barriers to development and implementation of geoscience curricula are based around inadequate resourcing and lack of trained and qualified geoscience teachers. Most ‘geologists’ will of course become geologists rather than teachers. This is often coupled with historical curriculum development issues in which geoscience has not been a significant part of curricula and perhaps not currently considered of high enough status to warrant funding and integration into science and/or geography courses. Indeed, the 2007 revision of the New Zealand science curriculum for example indicates the influence of global environmental issues and perceptions of what ‘expert’ panels consider being cognitively possible by students and guided by the politics of the time (Pooley, 2005). This is shown by a movement away from 'nuts and bolts' inductive constructivism of scientific concepts and towards broad, transferable skills and 'socialised science' conceptual development and for the geosciences, within an environmental Earth Systems:

> *" ..Earth provides all the resources required to sustain life except energy from the Sun, and that as humans, we act as guardians of these finite resources"*

And,

> *Students can then confront the issues facing our planet and make informed decisions about the protection and wise use of our Earth's resource.* (The NZ National Curriculum, 2007, p.28).

Globally, it is likely that geological science in schools (and universities) will continue to struggle for survival within science curricula and undergo various 'metamorphic' changes that integrate topical and fashionable (local and global) environmental issues and values. Lewis and Baker (2009) in their call for a new research agenda for the Geoscience education loudly express the deep seated issues of Geoscience education in the Unites States of America and elsewhere. They call for action research and the use of multiple and mixed method educational research to address the qualified teacher supply issue as well as asking for new directions in pedagogy and geocognition.

A prophetic last word on the future of geoscience (and geological science) education goes to David Thompson (1997).

> *Much will depend on the quality of the avenues of communication which are opened and maintained by groups which have access to power and finance and spare time to instigate, underpin, encourage and further professionalise individual teachers, school departments and teacher training institutions with their own national curriculum. (p. 173)*

3.9 Chapter Summary

This chapter addresses research question 1: international geoscience curricula design and implementation with particular case study reference to curricula in New Zealand.

There is little known about the formal status of geological science within an individual country's curriculum: there is a large variation in intent and implementation. It is also surprisingly difficult to obtain reliable information largely because of the many different locations and emphases of geological science in curricula. This chapter focused on geological science curriculum content rather than 'astronomy' content. Many Science curricula also appear to be in a relatively common state of revision and changes frequently occur which accommodate newer foci such as ESS or 'how the earth works' or 'environmental geology'. The IGEO has attempted to survey the status of geological science curricula globally but this remains a work in progress. Currently available information is outlined. This chapter identified key issues involved with geological science curricula and discussed similarities and differences between different countries.

The essential global problems facing geological science education within curriculum frameworks appear to be:

1. Obtaining sufficient trained and qualified teachers of geological science
2. Providing adequate resources and funding
3. Generating increased conceptual value in teachers' and politicians' perceptions of the vitality of the geological sciences to enable an educated population to make scientific links for informed decision-making about how the earth works, what it is made of, its history and what people do to it.
4. How to integrate meaningful geological science content in already overcrowded curricula in a time when science education internationally searches for ways to be meaningfully assessable and relevant for young people, especially those who do not extend their scientific literacy beyond the age of sixteen.
5. Establishing and maintaining complementary cross curricula relationships such as those between geography, environmental studies and biology.

Earth Systems Science as a teaching philosophy is discussed along with the issues associated with systems thinking and cognitive development. Earth systems science is successful at integrating environmentalism especially where fieldwork is well established and integrated with course structures (Ben-Zvi-Assaraf & Orion, 2009). However, this is largely at the expense of the essential tenets of geological science such as geological time, the fossil record, earth materials and structure. ESS also competes with geography and the social sciences in the many countries that share a British colonial educational ancestry. A comparison of a small country (NZ) (See Chapter 9 for details) with a national curriculum and qualification framework system, and a large federal state country (U.S.A.) with largely state control and an idealistic benchmark standards of content, illustrates key issues involved with the implementation of geological science content. Although the problems are similar, the scale and politics are hugely different. In essence, ESS sees the Earth as a context for teaching Science and Environmentalism (including socio-scientific issues) rather than geological science as a science.

It is unfortunate that the current (2009) NZ geological science curriculum content does not recognise the key elements that make geological science so vital: time, fossils, history, earth materials and structure. These scientific topics have been removed from the previous curriculum largely on the grounds that students and teachers are disinterested, that teachers lack resources and training, and that teaching geological history is beyond the ability of students, and that the content failed to generate motivated engagement. (Pollock, 2009). Lack of trained geoscientists, inadequate infrastructure and lack of resources are important factors but secondary school student diachronic geocognition of relative time and comprehension of evidence for geological history (especially when combined with well managed and appropriate fieldwork) is not. The only place where 'time' is involved in the NZ geoscience curriculum is at level 8 (final secondary school year and aged 17/18 years), but very few students (and schools) study geological science at this level (See Chapter 9 for details).

The current emphasis in the NZ curriculum for example is on processes, systems and human interaction in terms of natural hazard impacts, but most other known countries curricula recognise and teach the key geological science elements of

‘Deep-Time’, geological history, Earth materials and structure. It is unfortunate that there is, as yet, inadequate curriculum information from central European countries, South America and mainland Asia: time will tell. The 2010 IGEO conference in Johannesburg may update our knowledge base. What should 16 to 18 year old students leaving school know about geological science? According to the revised and realigned Level 1 (age 15/16 years) New Zealand Science curriculum and the *Planet Earth and Beyond* strand of 2010 (NZQA, 2009a), students should be able to demonstrate an understanding of:

(a) The formation of surface features in the SW Pacific, (http://www.tki.org.nz/e/community/ncea/docs/science1_13_int_sept09.doc)

This assessment standard involves internal effects of plate tectonic movement (as scarily displayed by the September 4th 2010 M_L 7.1 earthquake in Canterbury), volcanism, mountain building processes and external processes of erosion and weathering.

and

(b) The Carbon Cycle (http://www.tki.org.nz/e/community/ncea/docs/science1_14_int_sept09.doc), (NZQA, 2009b).

This assessment standard focuses on greenhouse gases, sequestering of carbon and system interactions, acidification of oceans and global climate change.

Is this geological science, environmental science or geography? Is there more to geological science and even general geoscience than this? If so, what content should students leaving school know about and how is it included in already overcrowded curricula where there are few qualified geoscientists and where there has been no tradition of teaching? Will removing geological science from external examination (See Chapter 9 postscript) be the final straw for learning about geology?

CHAPTER FOUR

ASPECTS OF CONCEPTUAL CHANGE

4.1 Introduction

> *"…a general recognition of the principles of punctuational change - leading us to understand that learning generally proceeds through plateaus of breakthroughs, and that important changes in our lives occur more often by rapid transition than by gradual accretion - might provide some distinct service in our struggles to fulfil the ancient and honorable Socratic injunction: know thyself."*
> (Gould, 2002, p. 957).

This chapter addresses key theoretical conceptual change aspects of research question 2: How do students aged between 12 and 40 years develop their conceptions of evolution and the fossil record, geological time and 3-D geological structures? It also briefly discusses evolutionary aspects of conceptual change theory from within a geological science framework. Analysis of questionnaire findings of what conceptions actually are for students is addressed in chapters 7, 8 and 10.

The ability to change our views of the world is surprisingly difficult because this involves a memory and understanding of the past, an understanding of the implications of the new and a willingness to take a risk. Perhaps that's a reason why people are so territorial and tribal - the risk of making changes has to be perceived to be not only intelligible and understandable, but also be of a potentially greater benefit than any current understanding. Making changes to a concept about observable phenomena in the world is essentially a cost/benefit exercise. Is the devil you think you know, better than the devil you don't? Or does it really matter? Conceptual change (CC) is about the way we all construct an understanding of the world through time and is an historical record of shifting conceptions with varying rates of intensity and longevity. It is a *coming to know* as well as a *coming to accept* and *persuasion* (Murphy & Alexander, 2004; Vosniadou, 2001a; Woods & Murphy, 2001). But what causes these shifts (or not) within an Earth Science context is a key subject matter for this thesis.

I wonder how William Buckland, Robert Jameson, Charles Darwin and Charles Lyell felt when they were finally confronted with irrefutable field and empirical evidence that was at odds to not only their personal world-view constructs but also selected western societies views of the early to mid nineteenth century. Gottlieb Werner and his neptunistic followers must also have been rocked (by hot lava and cold granite) when the Huttonian model of an ancient Earth (Baxter, 2003; Hutton, 1788; Jones, 1996; Repcheck, 2003) was firmly established by Playfair (Playfair, 1802). What exactly was it that made Charles Lyell abandon a young earth view (Gribbin, 2002) and embrace again the Huttonian vision of an ancient earth with modern geological processes being used to explain geological features, and now enshrined as the concept of uniformitarianism with a scattering of catastrophes thrown in? And what is ancient anyway? How did these influential thinkers (in the western world at least and not that easily either), change their conceptions of their worlds and translate them into perceptions for others to ponder?

It is also similarly clear that epistemological and historical factors rarely find expression within school or university courses (Thompson, 2000) as for example, in the place of plate tectonic theory within earth science curricula. Why did it take so long for people to abandon myths and legends as explanations of fossils (Jones, 1996) and the development of empirical science methodology over untested theory? What role does culture and genetics have to play in the business of changing conceptions at individual and institutional levels within a constructivist paradigm of learning? Posner, Strike, Hewson and Gertzog (1982) clearly outlined the essential prerequisites for conceptual change, and argument, abandonment and refinement has occurred ever since (Duit, 1999a, 1999b; Gess-Newsome, 2003a, 2003b; Pintrich, 1993; Tyson, 1997; Vosniadou, 1992).

The history of geological science is intimately connected to our changing conceptions of the way the world is, how it was and how it works. Uniformitarianism, biological evolution and Steno's principles of age relationships are fundamental concepts used in constructing a plausible, testable and fruitful view of how the planet works. This chapter attempts to look at some of these connections, place some conceptual changes into an earth science perspective and then relate these ideas to a view of how learners learn and teachers teach some of these fundamental aspects of geology. The notion of conceptual change as an evolutionary and ecological process via punctuated equilibrium within an educational setting will be explored (Aubusson, 2002; Gersick, 1991). Eldridge and Gould (1972), who have applied punctuationism to organisational science, do, however, correctly caution that punctuated equilibrium as a model is not likely to be the only mechanism of change and that it is always dangerous to apply a model from one domain (evolutionary biology) to another such as 'change management', and by inference, in the context of this thesis; conceptual change in learning and teaching within the Earth Sciences. Conceptual change implies the impact of a time dimension, and essentially, any analysis of a change in conception is measured through time. As an historical science, geology is not only uniquely set in its ability to explore the teaching and learning of what makes the planet tick but also the history of geology uniquely shows not only 'revolutions' in thinking about how the Earth works but it also chronicles the changes in conceptualisation of these processes. The 'permantisists', 'neptunists' and 'evolutionists' offer good examples, and these concepts will be discussed in more detail later. Conceptual change is likely to be revolutionary in outcome but evolutionary in process, and like studies of mtDNA in the evolution of modern human beings of the last 2 million years or so (Templeton, 2002), the mutation rates represent discarded (but dormant) conceptions. Perhaps this is why we have gone well beyond 'cold' conceptual change (Vosniadou, 2009)Conceptual change is about the how and why learning (or not) takes place and as a concept derived from early constructivist views of Piaget, Derrida and Foucault about the nature of reality (Matthews, 2003); the concept is too big to be easily pigeonholed.

4.2 Conceptualising Concepts

How does one conceptualise the world we live in? Music, prose and art are some ways, but when it comes to conceptualising the many integrated and interdependent processes that are involved in a scientific understanding of natural phenomena, things become a little more complex. In Cobern, Gibson and Underwood (1999) work on 9th grade student conceptualisations of nature, it is clear that the degree of scientific literacy that a student acquires is somewhat dependent on the extent to which a concept of 'science' is integrated into a students cultural and cognitive ecology. In Cobern et al's study (1999), it appeared that very little 'science' was invoked by these youngsters to ‘explain the world’: it was the students’ personal experiences with nature that counted. I suspect that this is not uncommon amongst adults as well. Indeed, a major research question addressed in this thesis is to demonstrate how much change occurs in key geological concepts across a wider age range. Clark (2004) discussed the connecting and planning power of concept mapping in the development of courses of instruction in structural geology but in this discussion, the concept map is used to illustrate the power of connecting ideas on conceptual change and which can be applied to geological ideas. It is the interconnectedness and visualisation of these connections that is important.

The diagram shown in Figure 4.1 summarises key aspects of the formation of pre-instructional conceptions, conceptions, misconceptions and perceptions. The use of pre-instructional terminology (Duit, 2003) harks back to the early days of the Learning in Science Project at the Waikato University Education department (Bell, 2005; Gilbert, Osbourne & Fensham, 1982). The legacy of this research is an integrated consideration and inclusion of student prior learning by teachers on the way they teach, especially within the sciences. However, personal experience of what once applied to high school students of the 1970’s and 1990’s does not appear to so easily apply to students of the twenty first century. The prior learning of today’s young digital expert is quite different to the analogue mechanist of prior times. Indeed, the gap between origin time of research and implementation of educational research findings appears to be widening as schools struggle with curriculum change, knowledge explosion and societal change (McIntyre, 2005).

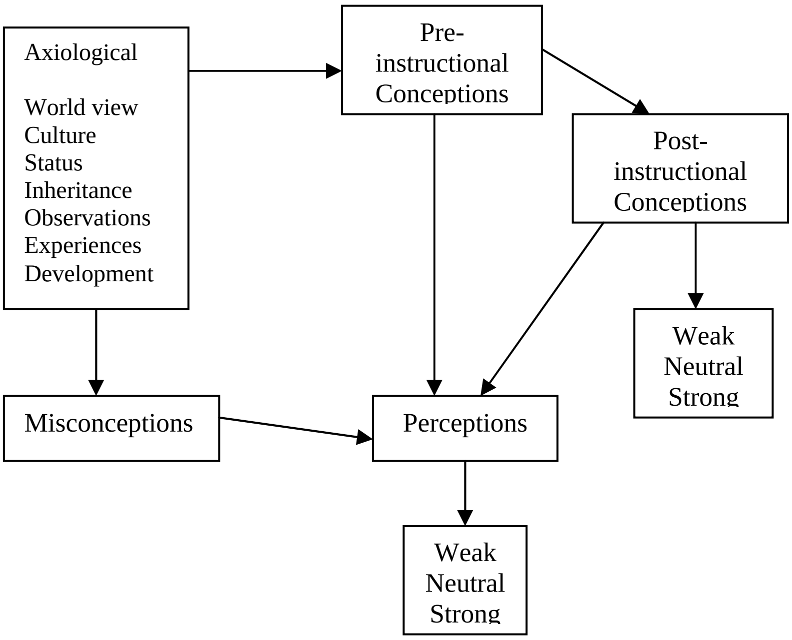


Figure 4.1. Concept map of pre and post instructional conceptions (Adapted and modified from Gilbert, 1982 and Duit & Treagust, 2003).

Conceptual change description and definition is diffuse in nature depending on emphasis, usage and author but Tyson et al. (1997) and Harrison and Treagust (2000) have summarised key historical events for the development of conceptual change theory (Figure 4.2) conceptualises the issue of conceptual status as a concept map. In practical terms, conceptual status is important because this is the position where the learner is along the road to changing conceptions of specific topics. Conceptual status is influenced by epistemic changes in experiences, information, organisation and knowledge.

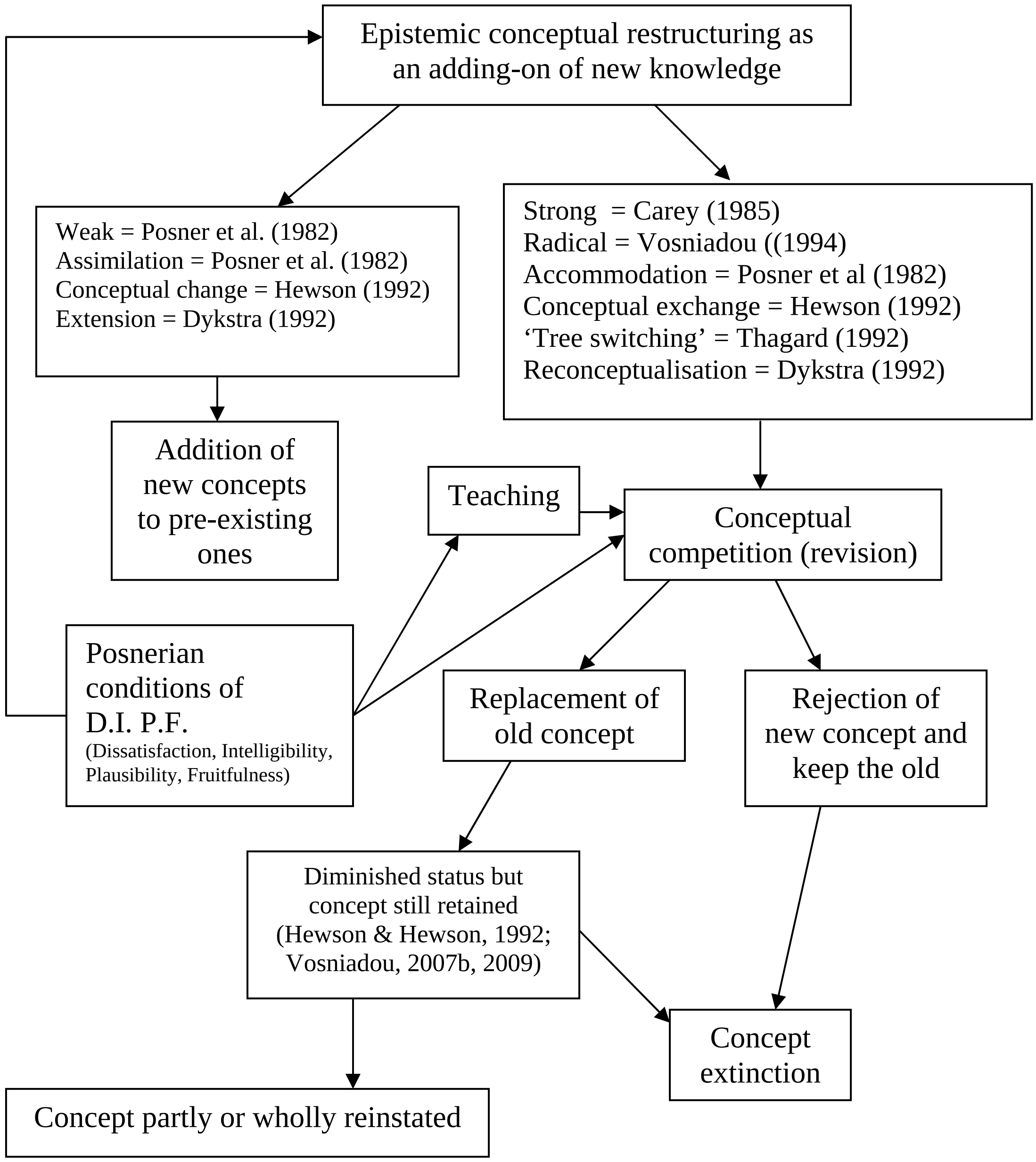


Figure 4.2. Historical summary of conceptual status.

What actually constitutes a conceptual change is a matter of debate (Carey, 1984; Dagher, 1994; Thagard, 1992; Vosniadou, 1994) and depends on prevailing worldviews. Essentially, conceptual change occurs at several levels analogous to biological macro and microevolution. However, conceptual change is not the same as knowledge addition. For example, it is one thing 'knowing' that basalt is different to granite, but it is quite another in comprehending that the difference is due to different cooling rates and chemistry. Indeed, the concept of rate is a complex one, and the idea that the rate of process itself may change at changing rates is even more baffling to many students. As White (1994) points out, concepts have fuzzy boundaries and conceptions are “systems of explanation” (p.118). Quite vague really.

Concept maps are powerful metacognitive techniques and have evolved from the original cognitive psychology work of Ausubel (1968). Since the mid 1980’s (Novak, 1984) the use of concept mapping has been integrated into teaching strategies and continues to be developed for use in assessment (Liu, 2004; Van Zele, 2004). Liu (2004) looked at using concept mapping for assessing and promoting relational conceptual change within a multidimensional framework. In particular, Liu used directed concept mapping or the “digraph” (p. 377) as a means of assessing conceptual change. Analysis of student concept maps focussed on relationships relevant to ontology and epistemology and within Posnerian conditions for conceptual change.

For Clark and James (2004), however, providing the big picture of a course of instruction in structural geology helped ‘pre-form’ student learning and reinforce prior conceptual understandings. Indeed, prior knowledge (Alao & Guthrie, 1999; Glasson, 1989) is considered to be an important predictor of conceptual understanding, at least at high school level. However, Alao and Guthrie also report that little is known about the effects of learner strategies and motivation on conceptual understanding and by inference, conceptual change. From a personal perspective, although concept maps as a strategy of teaching, are commonly used for ‘pre-testing’ students’ prior knowledge and reinforcement exercises, there is little evidence of concept mapping being used for assessment purposes in the manner established by Van Zele. Indeed, although Alao and Guthrie use knowledge tests as a measure of conceptual understanding, there is a considerable difference between searching for student prior conceptualisation and their prior knowledge. ‘Pre-testing’ does not search for concepts held by students; it finds (usually) only loosely associated key words that the learner knows about a topic. And besides, it is not easy, in a teaching sense, to actually deal with what is found out. Often ‘pre-testing’ is done for political reasons rather than educational ones. In other words, finding out and then being able to use this information on the depth of conceptualisation that a student has about a topic (such as the origin of granite or the concept of Deep Time) is a different game altogether. Perhaps this difference reflects the huge gap between educational research and classroom practice. Where is the 'fruitfulness' in adding yet another layer of assessment tasks on already overburdened assessment systems, and especially if standards based assessment (SBA) is used for high stakes? To illustrate a typical 'pre-test' concept map, the author asked his Year 11 students (aged 15 years), what they thought Earth Science involved. Two examples are shown in figures 4.3 and 4.4. Concept maps are synonymous with association maps.

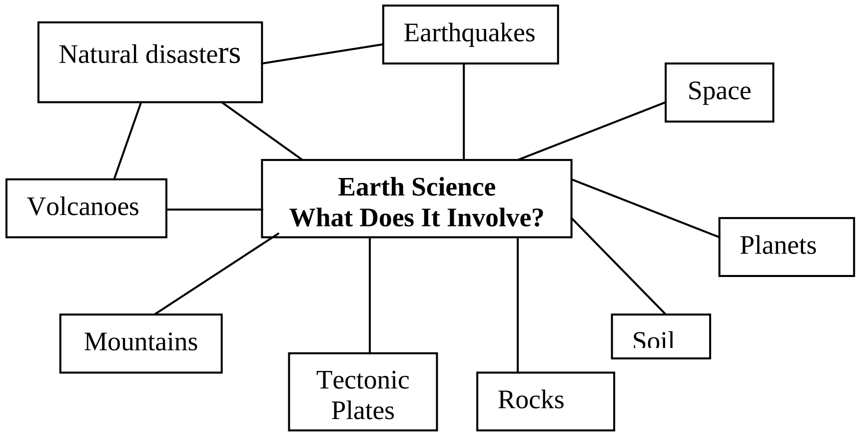


Figure 4.3. New Zealand Year 11 student B – male aged 15 years

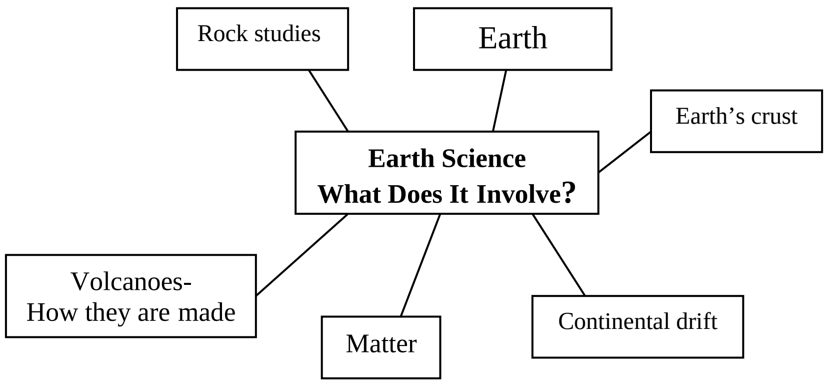


Figure. 4.4. New Zealand Year 11 student A – female aged 15 years.

Bearing in mind that these students have had about ten weeks of instruction in Earth Science in the previous two years and an unknown amount of time at primary school, what they express should reflect key ideas (hesitantly concepts) of their learning about the Earth. This appears to be the case but is discussed in more detail in Chapter 6. What was interesting out of the 14 examples was that there was a distinct lack of development of interconnections; maps just make one-word connections to the topic given although in the first example there is the beginning of a second layer or a subset of associated concepts, in Figure 4.4 a connection of volcanoes and earthquakes with natural disasters. But note that this student did not directly associate planets with space but that Earth Science involves planets and that mountains and volcanoes appear to be separate things especially if an association of volcanoes with natural disasters had already been established!

What is interesting about these ‘maps’ is that they represent prior knowledge that each student has associated with Earth Science as a subject of learning. This prior knowledge is based on 14 years of personal constructs and a little bit of formal instruction. To what extent these ‘ideas’ (facts?) are concepts is a difficult question to answer, but no doubt ideas are meaningful world views of these students at that time. One cannot construct a concept without knowledge. Fifteen year olds are certainly beginning to make deeper level connections within a science context.

Concept mapping is clearly a vital and useful tool (but not for all learners) in developing conceptualisations and is making important contributions to teaching and learning. In the development of web-based learning the use of concept mapping is particularly valuable (it gives an initial ‘bigger picture’ as shown by Clark and James, 2004) and is well illustrated in the development of the Earth Science programme at the Centre for Science Education, University of South Carolina. A good example of the use of a concept map in their programme on Earth Science is shown in Figure 4.6 and has been copied directly from their website on http://cse.cosm.sc.edu/hses/RthCrust/PlateTec/frames.htm. What is interesting in this concept map is that it shows a hint of connection between an important Kuhnian revolution in how we think about the Earth with evidence and usefulness of the theory of plate tectonics. No doubt, depending on the age of the student, extension of what is meant by “profound effect on geologic thought” can be included, as well as how the theory explains previously unexplained phenomena.

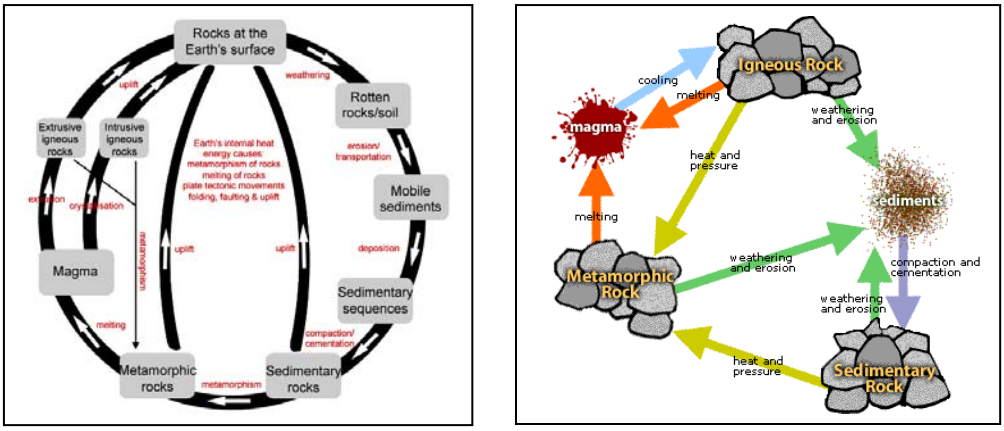


Figure 4.5. Examples of association concept maps of the rock cycle.

Teaching students how to 'read' concept maps is another issue altogether and learning style may be important in the teaching of how to construct a concept map For example, tactile and audio learners do not find concept maps particularly useful and tend to shy away from their use (Kostovich, Poradzisz, Wood, & O'Brien, 2007). Kostovich et.al. found that although their study indicated no learning style preference for construction of concept maps there is evidence for learning style influences on concept map interpretations. Perhaps a degree of spatial/visualisation is required as well as adequate training in their use is required. Although concept mapping is a powerful strategy for conceptualising concepts, it is not for everyone, and they can be time consuming and difficult to use for teaching and learning. Concept maps used by adults tend to be hierarchical and Safayeni, Debentseva and Canas (2005) make the case for the development of cyclic concept maps. Two concept maps of the rock cycle are shown in Figure 4.5. (www. earthscienceeducation.com/ and www.eos.ubc.ca/courses/eosc221/rock_cycle) is a good example of a cyclic concept map showing feedback loops and intra-conceptual relationships. The use of concept maps in analysing student abilities in linking ideas in systems thinking has been recently studied by Ben-Zvi, Assaraf and Orion (2005; 2009; Turcotte, 2006). Learning how to develop (and teach) system interactions, feedback loops and hidden dimensions is complex and challenging. Ben Zvi and Orion (2005) found that only 30−40% of respondents understood the cyclic nature of a system and that a cyclic perception only appeared from students who had previously developed an ability to identify dynamic relationships within the system.

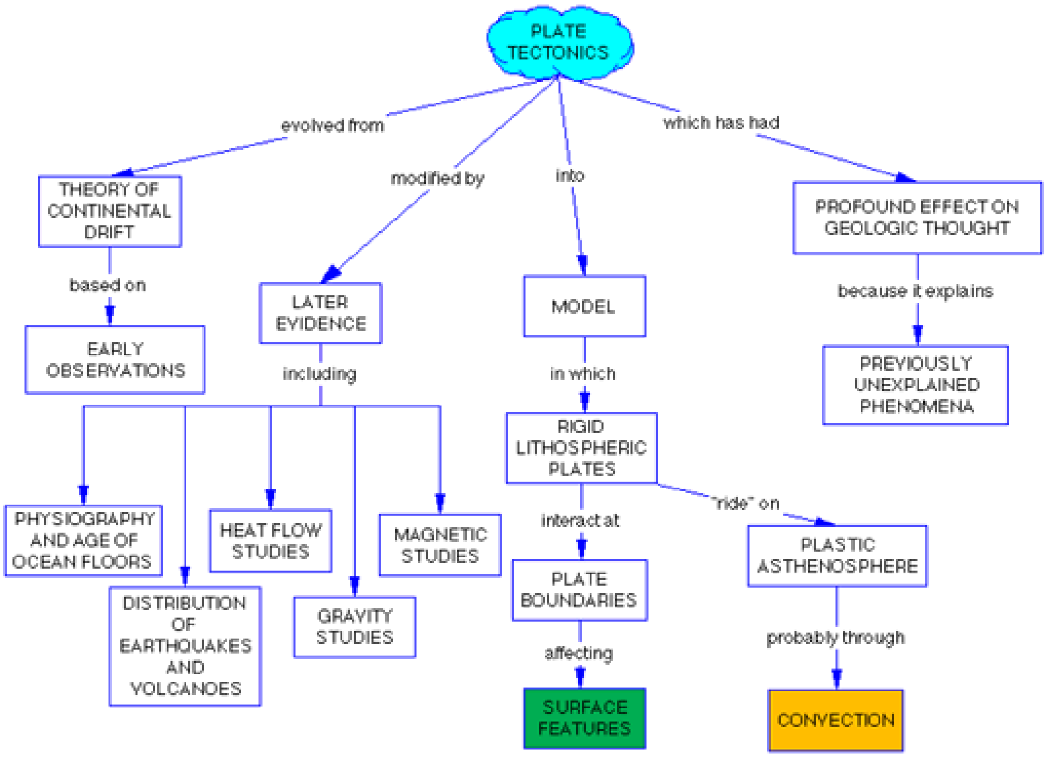


Figure 4.6. A concept map of plate tectonics from (CSE, Univ. S. Carolina).

Note that the concept map of plate tectonics shows a typical hierarchical system, whereas the rock cycle diagram is closed and has feedback loops. In another kind of 'concept map' (adapted from Pintrich et al. 1993), conceptual change can be viewed as a kind of Venn diagram (Figure. 4.7). In this diagram, overlapping boxes indicate interrelationships, but not intensity of causality. The challenge is to connect the isolated Posnerian CC conditions with effective conceptual change.

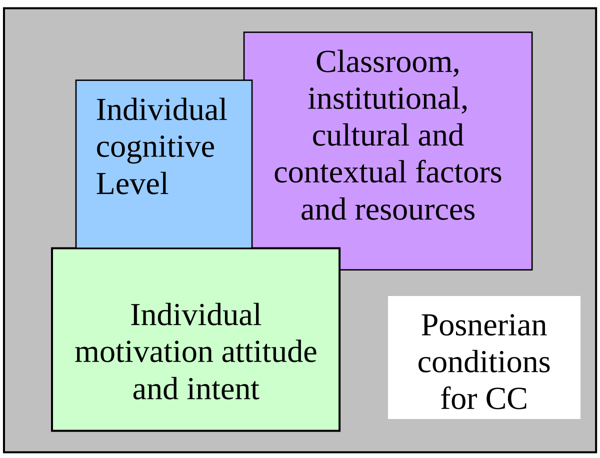


Figure. 4.7 Venn style diagram of conceptual change (Adapted from Pintrich et al. 1983).

Conceptualisation of conceptual change has moved since 1993 (and 1982) towards a much more inclusive, diverse and complex understanding (including intentional conceptual change) of how students (and teachers) construct their view of scientific world. Duit and Treagust (2003) and Treagust and Duit (2008) neatly summarise the ‘limits’ of the ‘classical conceptual change approaches’ and show the complexity of conceptual change. In an effort to bridge the widening gaps between the classroom and the theory, this complexity may well benefit from an application of ‘cladistic’ thinking and metacognitive approaches. Indeed, Georghiades (2000)considers that teaching metacognitive skills to younger students (8-11 year olds) would improve the longevity and transferability of their conceptualisation processing. But then puberty and testosterone gets in the way at the high school level, and job security takes over from there!!

The idea of intentional conceptual change has been extensively addressed by Sinatra and Pintrich (2003). Intentional conceptual change implies that not all conceptual change is intentional and that some learning cognitively occurs spontaneously (that is, without intent), as phenomena are observed and measured. There is also the possibility of the intention not to change. The question is really one of ‘to what extent is intentional conceptual change part of the learning process? And, what drives the motivations for ‘intent to change (evolve?) concepts of, for example, natural phenomena such as the causes of earthquakes and tsunamis and crystallisation processes? Learning is intentional but not always successful and meaningful (Figure 4.1). Mixed in with this idea is the notion of conceptual status (Harrison, 2000; Hewson, 1992) whereby concepts held by the learner are kept, discarded, modified or exchanged in varying degrees according to personal constructs and/or learning circumstances or “intellectual position” (Harrison & Treagust. p.375). Although success may be in the eye of the beholder, it is not always successful in the eye of the ‘scientist’. Clearly, conceptual change is much more than just ‘conceptually’ going from process to intent. It is the ‘change’ bit that is important to teaching and learning (see later section on conceptual change and the teacher). However, as an example, a shift from thinking about the Earth as having the continents fixed in position and fossils as being inorganic, to the opposite concepts required a change in cognitive and psychological perspectives within a cultural setting. And this was in the adult learning world! This accepted shift in thinking about explaining the changing nature of the planets geological history also required time – something that the classroom teacher does not have much of. And, in the cases of Hutton and Darwin, without the aid of a Playfair or a Huxley, even more time may have been required! Perhaps more effort to understand resistance to conceptual change would be more fruitful for learning?

The case of James Hutton is a particular case in point and illustrates the personal and cultural complexities involved in intentional conceptual change. For example, without the cultural climate of an evolving Scottish Enlightenment, the deistic teachings of the mathematician Colin MacLaurin, his connections with the workings of the human body with a recyclable and beneficent Earth (Hutton's medical thesis from Leiden University was on the circulation of blood), and the personal drive to 'make a mark', Hutton would not have been able to conceptualise an Earth that had "no vestige of a beginning nor prospect of an end" (Hutton, 1788). Hutton saw a beneficent Earth through his work as an innovative farmer breaking in the soil, but he must also have been sufficiently dissatisfied with contemporary biblical explanations for the timing and origins of the Earth and its features. His conceptual journey took a long time and was dominated in a heroically scientific search for evidence, but most of all, his ancient Earth concept and uniformitarianist mechanisms appeared suddenly (punctuationally?) on the geological stage in a classically punctuated fashion. Although he was aware of volcanoes and earthquakes, it was a pity that he lived where there was no active volcanism and an even greater pity that he was not alive in 1880 when Scotland had its largest earthquake (http://www.earthquakes.bgs.ac.uk/.) From a conceptual point of view, Hutton began with experiential *sensations* and information gathered about what he saw in the field that allowed him to develop *perceptions* about this information. These perceptions then led him to develop *conceptions*. Hutton had the motivation and intention to change his understandings of how the soil and the mountains got there and he went on to develop the concept of uniformitarianism later to be used so effectively by Charles Lyell. These conceptual changes reveal an evolutionary process. Although not well presented, Hutton's conceptual change about the history of the Earth was not well received in the context of his time (Baxter, 2003), but a fuller understanding and verification of his conceptions had to wait for the twentieth century.

Intentional conceptual change clearly involves learning and its associated cognitive processing within a constructivist paradigm, but it is the connection with the intent to learn and to actually take on shifts in conceptual development that measures the degree of learning. Although teachers do make a difference, issues of student motivation, self-esteem, drive and cognitive abilities seriously influence individual learning outcomes (Vosniadou, 2007). Intent to learn (as measured by a perceived degree of conceptual shift in individuals and institutions) is constrained by sociological, cultural and individual motivations and by current dominant worldviews of science and its utility in society. Conceptual change is laden with value clashes; this is what makes the learning process complex. To use an evolutionary analogy for speciation, Dawkins (2004) discusses and defends the notion of directional progress, but directional progress within conceptual change is only seen looking backwards. Idealistic 'scientific' concepts eventually accepted by learners are unpredictable when looking forward from the learners' point of view in space and time. A progressive, value-laden view of conceptual change is a prejudicial view of how learners learn (and how teachers should teach). Recognition of this has led to the development of a multidimensional approach to understanding conceptual change (Tyson et al. 1997). However, it is also much easier to assess a predetermined path for accountability than to assess the real conceptual changes that occur in an individuals learning. The challenge of teaching science is to fashion the manageable catalysts that move conceptions in desirable directions. But the directions are not predictable nor necessarily linear or progressive. Perceptions are, in a sense, the shapes that are left after the bubbles of concepts have been rearranged, either by teaching intent or otherwise.

The notion of persuasion in the evolution of individual conceptual change is important. Persuasion is also intimately connected with intention and assessment, and attempts to measure the differences (not always very successfully). The success of persuasion in catalysing conceptual change is linked strongly to individual belief systems, perceptions, culture and upbringing of both the learner and the teacher. Murphy and Alexander (2004) ably point out that persuasion is an interactive process in which individual perceptions are changed. As the catalyst, this is clearly what teachers try to do, but measuring the effectiveness of persuasion on conceptual change is validly and reliably difficult to do.

Petty and Cacioppas' (1986) early views on the central and peripheral routes taken by learners towards change would suggest that the learners predisposition to change is in command and that the central route is more lasting and powerful than the peripheral.

4.3 The Geoscience Concept Inventory

Following the development of conceptual test inventories for biology and physics (Anderson, 2002; Pollock, 2004), Libarkin, Anderson, Boone Beilfuss and Dahl (2002) and her team have developed a geoscience concept inventory (GCI) in an attempt to establish a measure of conceptual benchmarking for students of the Earth Sciences. Although validity and selection of questions is debateable, the GCI attempts to elicit existing conceptual information about topics such as volcanoes, mountains, Ice Ages, earth's interior, earth's magnetic field, formation of the earth, geological time and sequencing of geological events. As an example of an application of GCI (Dahl, 2005) aimed at a group of pre-service and in-service teachers found that over 60% of both cohorts thought that single celled organisms were already existing when the earth first formed.

Other 'misconceptions' reported in Dahl et al.'s work are:

- The most accurate method of dating rocks is by Carbon dating.
- Height of mountains can be used calculate the age of the earth.
- Volcanoes are associated with tropical climates.
- Gravity is caused by the earth's magnetism.
- The extinction of the dinosaurs ranged from 150 mya to 200,000 years ago.
- The first humans appeared from 10,000 years ago to 2003 years ago.

The use of conceptual inventories for capturing snapshots of student conceptual development may play an important future role in the development of curricula and content delivery. For example, there is little point in developing a curriculum if the concepts involved are beyond the cognitive levels of the learner. As Libarkin (2006) shows,

> "This disconnect between faculty perceptions and realities of the models that students are bringing with them to the classroom suggests that identifying and

> discussing student ideas is a vital part of instruction as has been suggested by K-12 researchers (p.7)."

How this is actually achieved and acted upon in a 'live' school and classroom situation is another matter altogether. Experience tells me that this sounds good on paper but not so easy and dubiously effective in reality (i.e. when divorced from the research situation). The problem is that there are too many other variables such as individual motivation, intention, cognitive ability and socialisation issues that are not controllable.

It is useful to have a reasonable understanding of what students are able to do based on objective and validated information before proceeding to deliver a topic of learning. A concept inventory such as the GCI is one tool that can provide information needed for not only for understanding where individuals are at, but also for curriculum development. It is important to know what kind of 'best practice' pedagogy can be used for the delivery of content on topics such as plate tectonics, earthquakes, volcanism, the rock cycle and geological time. The teaching of Science in an Earth Science context developed by the Earth Science Education Unit at Keele University (www. earthscienceeducation.com) is a case in point. This is constructed on the conceptual development of teachers and learners. Indeed, the development of concept tests is based on Bloom's taxonomy for conceptual application, analysis and comprehension and has been used to assess (formatively and summatively) and to aid development of conceptual understanding in undergraduate geology classes (McConnell, 2006). An important trade off in using concept tests for formative and summative assessment is that of time. In a secondary school for example, the three to four extra hours that is imposed upon an already crowded subject content may not be perceived as 'fruitful'. However McConnell et al. (2006) report quantifiable improvements in student understanding and engagement. The 'fruitfulness' has to be taught and managed. In their discussion of 'interactionist' (affect, belief and extra - rational) factors of conceptual ecologies of pre service teachers understandings of the nature of science Southerland et al. (2006), confirmed the complexities of conceptual change.

An example of a recent conceptual change difficulty is that reported by Selles-Martinez (2006) at the International Geoscience Education (IGEO) in Bayreuth. Selles-Martinez suggests that students' conceptions of the mantle are influenced by inaccurate textbook portrayal of the mantle as a liquid. Students apparently conceive the mantle as a liquid because the explanation provided in textbooks consistently show convection currents generated in a saucepan of water. It is also likely that students' conceive the mantle as two dimensional rather than three dimensional as a result of simplistic two dimensional textbook diagrams. A typical example of this concept is shown in Figure 4.8 (http:// pubs.usgs.gov/gip/dynamic/unanswered.html).

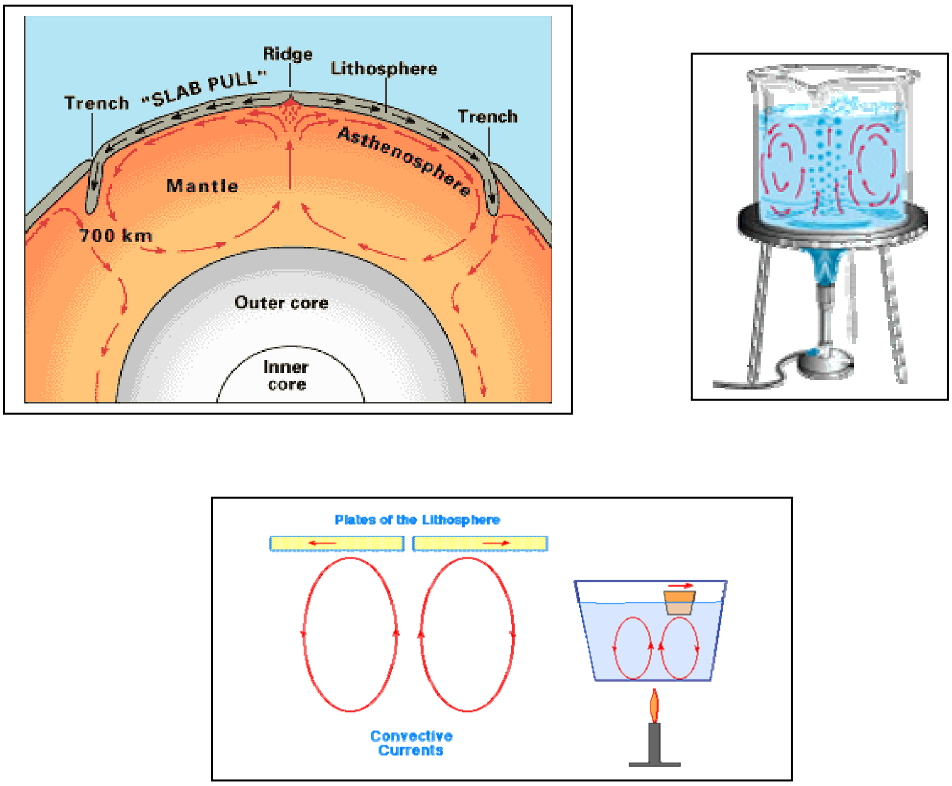


Figure 4.8. Textbook conceptual diagrams for geological convection cells.

This kind of diagram is unlikely to mean a lot to a 14 year old except for them to make the clear connection between boiling liquid water and the earth's mantle. Where is the exemplar 3-D diagram of mantle convection?

4.4 Conceptual Change and Punctuationism

Assembling and constructing ideas about observable phenomena is time and culture dependent. Is conceptual change directionally progressive or just responsive to selection pressures? Does conceptual change evolve? If so, how and why?

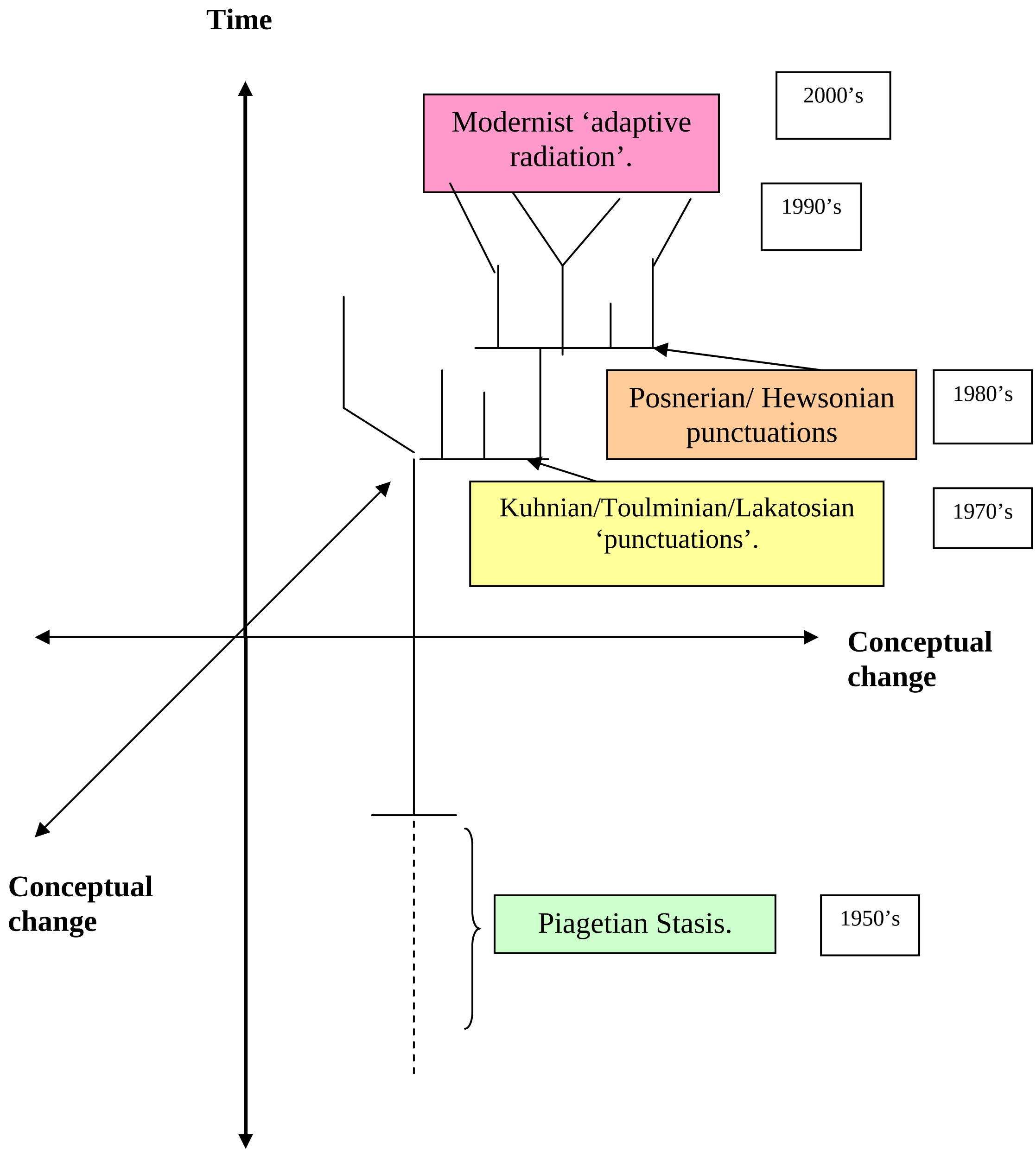


Figure 4.9. A punctuationist model for conceptual change (adapted from Eldredge and Gould, (1972)).

As mentioned previously the ‘change’ in conceptual change **is time related** and it is only by viewing conceptual change through time that an appreciation can be made of the role this model has in current understandings of learning. Figure 4.9 is an attempt to show the broad historical development of the conceptual change model of learning. It is placed within an evolutionary punctuationist framework based on the original diagram from Eldredge and Gould. It is interesting that the concept of evolutionary punctuated equilibrium as used to explain aspects of the fossil record was developed contemporaneously with Thomas Kuhn’s work on the mechanisms of scientific revolutions.

Indeed, Gould (2002) goes so far as to state that Kuhn’s work on scientific revolutions was the single most important influence that he received on the development of the theory of punctuated equilibria.

> *… if I were to cite any one factor as probably most important among the numerous influences that predisposed my own mind toward joining Niles Eldredge in the formulation of punctuated equilibrium, I would mention my reading, as a first year graduate student in 1963, of one of the 20th centuries most influential works at the interface of philosophy, sociology and the history of ideas: Thomas Kuhn’s ‘The Structure of Scientific Revolutions’, 1962.*
>
> (Gould, 2002, p.967)

The notion that conceptual change is gradualistic, directional and progressive is implicit in the idea that learning is constructed by moving from one concept (or misconception) to another concept (or misconception). Indeed, understanding what is meant by ‘change’ is important. Change can be seen as a restructuring of prior knowledge (Duit, 2003), or it can be seen as an exchange of pre-instructional conceptions. Duit and Treagust (2003) suggest that the latter is a misinterpretation. In a Gouldian analogous sense, changing specific scientific conceptions could be interpreted as the equivalent of allopatric speciation events and subject to many selection pressures (Mayr, 1982). Understanding the connections and drivers of these selection pressures underlies how conceptual change may occur. It remains to be seen which of the modernist adaptive radiation models will survive and spawn their own periods of conceptual stasis, extinction or continued radiation. How much 'spin' can be put on conceptual ecologies, status and intentional change? Will multi - dimensional framework models survive or will conceptual ecology models, status and intent and persuasion models adaptively radiate? In any event the real world of classroom interaction and contingency will likely be the controlling factor. In other words, the gap between classroom manageability and environment and conceptual change theory is likely to be too large for meaningful change. The data shown in Table 4.1 is another way of making sense of a brief history of the punctuations in conceptual change evolution. But tables of information tend to be 'cold' and do not often place ideas into any contextual framework. Without this, the richness of historical intelligibility is lost.

Table 4. 1. Summary of key 'punctuations' in conceptual change evolution.

Proponents	**Key concepts**	**Date**
Piaget Derrida Foucault	'Stage'theory, interviewing and cognitive psychology Early constructivism	1950's 1960's
Toulmin Kuhn Thagard Lakatos Von Glasersfeld	Conceptual ecologies 'Scientific revolutions' 'Conceptual revolutions' } Modernist constructivism	1970's
Gilbert et al. Osborne et al. Posner et al. Hewson et al. Strike et al.	Knowledge of the pre instructional worlds of learners. Learning in Science Project (LISP) in New Zealand. Conditions for 'cold' conceptual change Increased use of learner meta cognitive levels Beginning of CC approaches to teaching Conceptual ecologies revisited	1980's
Hennessey et al. Hewson et al. Vosniadou et al. Treagust et al.	Merging of social constructivism and culture Multiperspective epistemological frameworks extend the concept of conceptual change Multi dimensional conceptual change	1990's
Pintrich et al. Sinatra et al. Duit et al. Limon et al.	Complexity of intentional CC and persuasion Merging of CC with cognitive psychology	2000's

Although over 10 years ago (but 20 years since Eldredge and Gould), Gersick's (1991) views of revolutionary change theory in organisational systems are conceptualised as a punctuated equilibrium where there are long periods of stability and stasis of current models only to be changed by rapid 'adaptive radiation' of new ideas. Gersick applied punctuated equilibrium theory to several research areas including individuals, groups, biology, science and organisations and found commonalities of mechanisms for change. The key understanding from Gersick's work was that change in each of the commonalities did not appear to be linear, progressive and directional but rather, punctuational. This 'directionality' concept in issues concerned with conceptualisation of geological time, the fossil record and evolution is further discussed in chapter 6. Recent work by Lyytinen & Newman (2006) has also applied evolutionary punctuational ideas to information system and development change, with its attendant socio technical implications. It is suggested here, that shifting scientific concepts for students of any age evolves as a punctuated mechanism and is controlled by cultural, sociological and individual selection pressures in the 'need to know', and obeying the laws of minimum effort and risk. This 'need to know' involves not only an individual and institutional intention to change but also one that follows the 'cold Posnerian conditions' for conceptual change. There also has to be an ability for institutions and individuals to be able to change.

New knowledge and understanding of how the brain learns (or not) is an example of a selection pressure for conceptual shifts. It is interesting that the punctuated equilibrium model for conceptual change has not been applied to teaching and learning. For example, Kwon and Lawson (2000) clearly demonstrated the connection between maturation of prefrontal lobe activity and social experiences and the ability of 13 to 16 year olds at recognising and rejecting irrelevant science concepts and developing hypothetico-deductive reasoning. This of course has major implications for spatialisation skills and conceptions of time in geological reasoning. This is especially important (Thatcher, 1987), as this growth spurt seems to occur primarily in the prefrontal lobes at ages 14 to 16 years. It is this variation in prefrontal lobe development that makes teaching (Kwon, 2000) such an interesting occupation! For Treagust and his colleagues, (Tyson, Venville, Harrison & Treagust 1997) in asking the question "Is the age of the individual relevant to a theory of conceptual change" (p.395), the answer, based on modern understandings of how the brain develops and works, has to be yes. Conceptual development of geological time is to some extent age dependent, as is the visual–spatialisation skills needed to interpret geological structures This aspect has important implications for earth science curriculum development and reform (Liben, Kastens, Agrawal, Christenson. & Myers, 2009).

In the multi dimensional modernist world of Tyson et al. (1997), which recognises the complexity of conceptual change, it is unlikely that conceptual change unfolds in a Judeo-Christian, progressive, and directional sense where one misconception is corrected by good teaching practice to miraculously change into the 'expected' newer, more sophisticated and 'scientifically' acceptable concept. This parallels the directionality and progressivism so ardently argued against and considered by Eldredge and Gould in their views of biological evolutionary mechanisms by punctuation. This helps explain why it took so long for Hutton's concept of an ancient and unimaginable 'deep time' world to be accepted by the scientific community of his time. Punctuated evolution is characterised by long periods of (conceptual) stasis followed by rapid diversification. These changes operate at multi levels from large-scale paradigm shifts (Kuhn's 'scientific revolutions') to individuals' daily conceptual shifts. Either way, change in thinking evolves through time. When Tyson et al. (1997) posed the question as to whether the age of the learner matters, their conclusion was yes. Furthermore, conceptual change can only be interpreted (and implemented) within a time frame. The idea of an extra terrestrial lump of rock (bolide) impact as an explanation of the great extinctions at the end of the Cretaceous period in 'our' times or the final destruction of the diluvial (water derived) Wernerian concept of rock formation took time to develop and evolve. Acceptance (and intention to accept) is a critical aspect of conceptual change.

Duit and Treagust (2003) briefly mention what is meant by the 'change' in conceptual change, and indicate (along with Matthews, 2003) that construction of knowledge is different to construction of beliefs. This of course has implications for classroom teaching of science knowledge and science concepts. Duit and Treagust consider conceptual change to be a restructuring of prior knowledge but have often been misinterpreted as changes in student pre-instructional conceptions. These ideas can be 'translated' or reconceptualised into visual statements (Figure 4.10). In 3.10, Longbottom's work on reconceptualising science education (Longbottom, 1999), he makes pertinent reference to conceptual change as comparing the thinking of learners to that of 'scientists'. Thagard (1991) takes the alternative view that relationships between competing concepts builds new knowledge rather than changes to the concepts themselves.

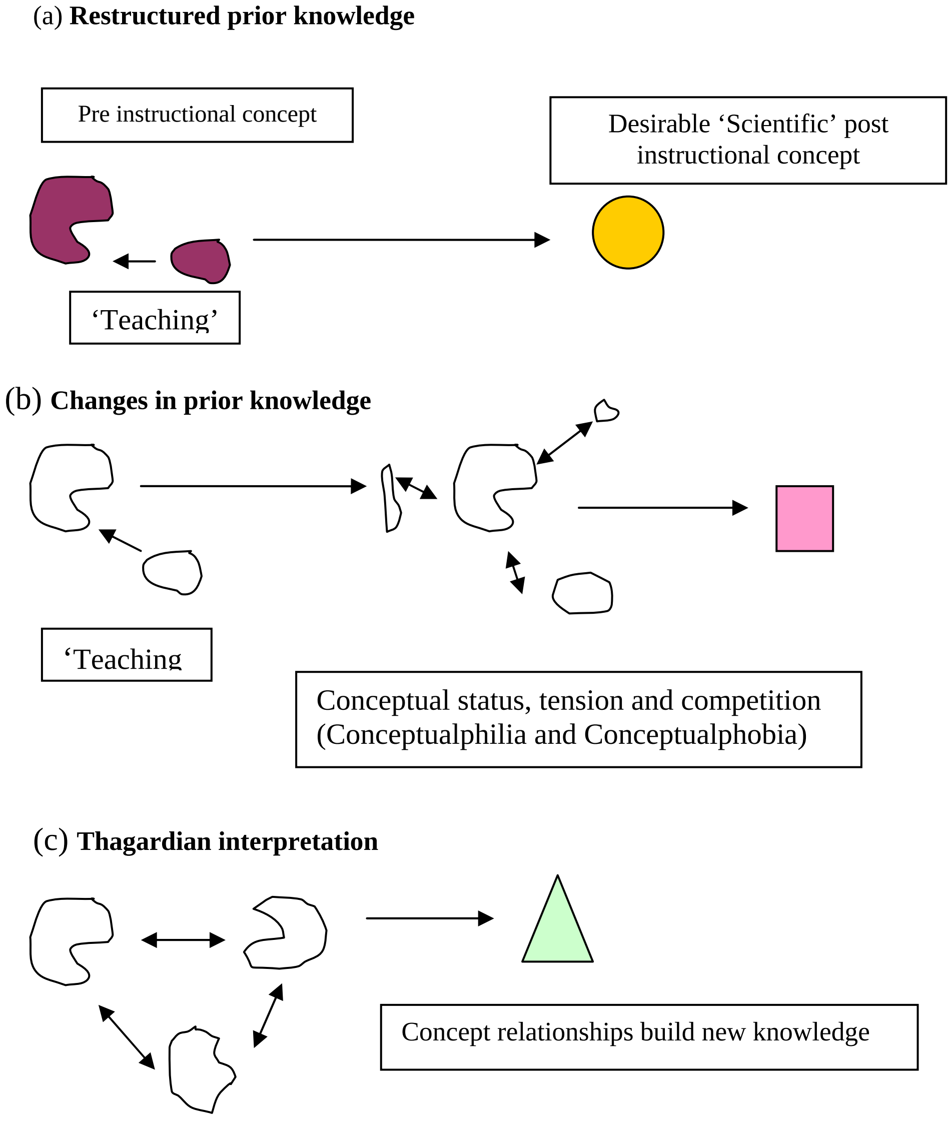


Figure 4.10. The 'change' in conceptual change.

Translating words into pictures demonstrates how reconceptualising a concept is such an important part of the learning process and forges new neuronal links in cognitive processes. This brings a whole new meaning to 'forcing square pegs (student conceptions) into round holes (scientific, political and institutional conceptions)'.

4.5 Conceptual Change and Geological Time

As implied earlier, the conceptual development of geological "deep time' has been one of the crucial concepts in human understanding of how the Earth has come to be a key element of what geology is all about. No other discipline of learning involves time is such a way, and the discovery of the Earth's age is one of the great contributions geology has made to our understanding of the history of the Earth. It seems that a number of key conceptual changes at various epistemological, ontological and social/affective levels, within a multidimensional Posnerian framework are at work for this to happen. These conceptual changes were themselves embedded in their own time frame and in the end, the empirical evidence became too great to ignore (Eicher, 1968).

Conceptual change in our understanding of geological (Deep) time has followed a punctuated pattern. Up to Hutton's seminal work (Hutton, 1788), concepts of geological time were dominated and controlled by politico/religious teachings and visions of a young and fixed Earth (Gould, 1987). Time was viewed in a temporal and unchanging way with the concept of geological time yet to come. This temporal and religious concept of time held for centuries but became seriously shaky when the true nature of fossils became clear and Nicolaus Steno (Cutler, 2004) developed the rules of stratigraphic superposition and cross cutting relationships in understanding the nature of relative time. On top of this, the Wernerian neptunists' concepts of rock being precipitated from water lost to the plutonist empirical evidence gathered by Hutton. The concept of 'Deep Time", first coined by McPhee (1981), was the product of a long period of enlightened thinking after the planet had been removed from its centrality in space and thought. To this end, the data in Table 4.2 show the key authors in contemporary times for the conceptual development of geological time. It is beyond the scope of this thesis to provide historical details but suffice to say, these people represent the key conceptual changes. It is remarkable that the period between 1665 and 1875 paved the way for the modern interpretation of Earth history. This essentially involved a conceptual change from short-term fixist and temporal thinking about the age and origins of the Earth to a dynamic and old Earth. By placing the key researchers in their life times relative to each other, a better picture of the complexity of conceptual change can be appreciated.

Table 4.2. Life spans, authors and geological concepts.

Author	**Relative Life Spans**	**Key Concept Held and Promoted**
James Ussher	1581-1656 = 75y	Based on biblical generational chronologies, Earth is 6000 years old
Nicolaus Steno	1638-1686 = 48y	Described the rules of relative stratigraphic ages.
Comte de Buffon	1707-1788 = 81y	Idea that Earth is older than 6000y based on cooling rate of iron (a minor player).
James Hutton	1726-1797 = 71y	Based on 'plutonist' ideas of molten material and recycling, the Earth is very very old and explained by uniformity of process (uniformitarianism).
John Playfair	1748-1819 = 71y	Rewrote Hutton's work
Abraham Werner	1749-1817 = 68y	All Earth's materials were 'neptunist' in origin and precipitated out of water.
Georges Cuvier	1769-1832 = 63y	Earth formed by catastrophic processes
William Smith	1769-1839 = 70y	Similar fossils identify rock strata as the same age. Produced the first geological map.
Charles Lyell	1797-1875 = 78y	Championed Hutton's uniformitarianism, where the present geological processes and rates explains Earth history.
Jean B. de Lamarck	1744-1829 = 85y	Characteristics of living organisms were acquired through use.
Charles Darwin	1809-1882 = 73y	A very long Earth history required to accommodate evolution by natural selection.
Alfred R Wallace	1823-1913 = 100y	Co-founder of evolution by natural selection.
James Dana	1850-1892 = 42y	Contraction by cooling explained the permanent nature of the Earth.
Alfred Wegener	1880-1930 = 50y	Continents move horizontally

The information presented in Table 4.2 places in time and social context the conceptual leaps that took place in the evolution of an understanding of the great age of the Earth within an epistemological and ontological framework of the authors' times. Figure 4.12 attempts to place the key authors (and their concepts) into their linear lifespan relationships because conceptual evolution needs to be seen in the context of the authors' lifetime worldviews and in their real time context. Conceptual change cannot be separated from their historical and contemporary contexts, and as stated by Vosniadou (2003) "in order to fully understand conceptual change we have to investigate how individuals learn in social contexts" (p.402). Vosniadou went on to describe the need to understand other variables involved in conceptual change such as individual cognitive, social and motivation, educational settings and the broader cultural interactions.

Apart from the incorrect 'old Earth' views of Aristotle (who was also terribly confused about the origin of fossils), Herodotus, Theophrastus, Leonardo Da Vinci and a few others, the period from about AD1600 paved the way to a rapid and influential period of change about the way people viewed the history of the Earth. It is not surprising that the work of Nicolaus Steno, James Hutton (and his 'bulldog' Playfair), and Charles Lyell are regarded as the founders of 'Geology' as a science and who set the stage for the rapid 'adaptive radiation' of modern conceptualisation about the Earth. Clearly, the concept of an Earth that is fixed, temporal and at the centre of the universe, to one of an Earth that is dynamic, limited, and a speck of dust in the Universe did not happen in a progressive, linear, A to B type fashion. When properly scaled into time, the explosion of understanding about the Earth in the "age of enlightenment and renaissance' came as a punctuation on a long stasis of temporal and ignorant thinking of the dark ages, classical times and the earlier myths and legends and the wonderment of observed natural phenomena and objects (Figure 4.11). The Scottish enlightenment was indeed a conceptual explosion that led to adaptive radiation of the scientific theory of evolution. Concepts are like bubbles that expand, break or fuse, and to be properly understood retrospective conceptual changes have to be seen in the context of their times (social/affective factors) and with hindsight power of evidence and persuasion. The masculine Euro-centric nature of these great scientific conceptual leaps (in the Kuhnian sense) is well noted, but Murray (2003) also points out that this Euro-centric enlightenment is real even when the quality and quantity of research is taken into account. The geological conceptual challenges of today were generated in the 18th and 19th centuries and they centred on the conceptualisation of deep time, fossil records, stratigraphy and evolution, and a better understanding of the interior of the earth and the forces that govern its operation.

4.6 Conceptual Ecologies

In an attempt to place conceptual change in a metaphorical and analogous context of a living biological ecological system the notion of a conceptual ecology was used by Aubusson (2002), to help effect and explain the change process for a school shifting from a 'transmissive' approach to a constructivist approach to science teaching and learning. Here, the teaching and learning of science was seen as an evolving ecological system controlled by 'environmental' factors and interactions: a potentially useful way of conceptualising conceptual change. However, what Aubusson found was that "planned innovation is an inappropriate way to attempt change, since the consequences of implementation are unpredictable" (p.43). Besides, there are so many independent variables involved with change that this is hardly surprising. Nevertheless, an ecological approach to understanding conceptual change greatly assists in providing an understanding of many interdependent and interacting 'chains and web' variables. As an example, Figures 4.13 and 4.15 attempt to illustrate a different perspective by scaling today's rapid conceptual radiation about the nature of fossils and geological time into a linear view of the last 22,000 years (and not in conventional geological relative time order). It also attempts to apply punctuationism ideas to a different scaling of conceptual changes of ideas about fossils. The conceptual punctuations of the last 400 years is striking when placed into this context, and illustrates the unique power of Deep Time thinking that geology has given us and that when conceptual ideas are scaled into real time, concepts (like biological species) evolve and rapidly adaptively radiate.

Conceptual ecologies also involve dissemination of conceptual information. For schools this usually means textbooks and DVD's. An analysis of misconceptions, errors and oversimplifications of geological concepts and processes such as plate tectonics, weathering and sedimentary rocks (King, C, 2009) reveals a significant set of geological misconceptions that are perpetuated and reinforced in textbooks largely as a result of authors who do not have clear conceptual understandings of geological science. Do teachers do the same thing in the classroom when transliterating complex earth systems into simple systems?

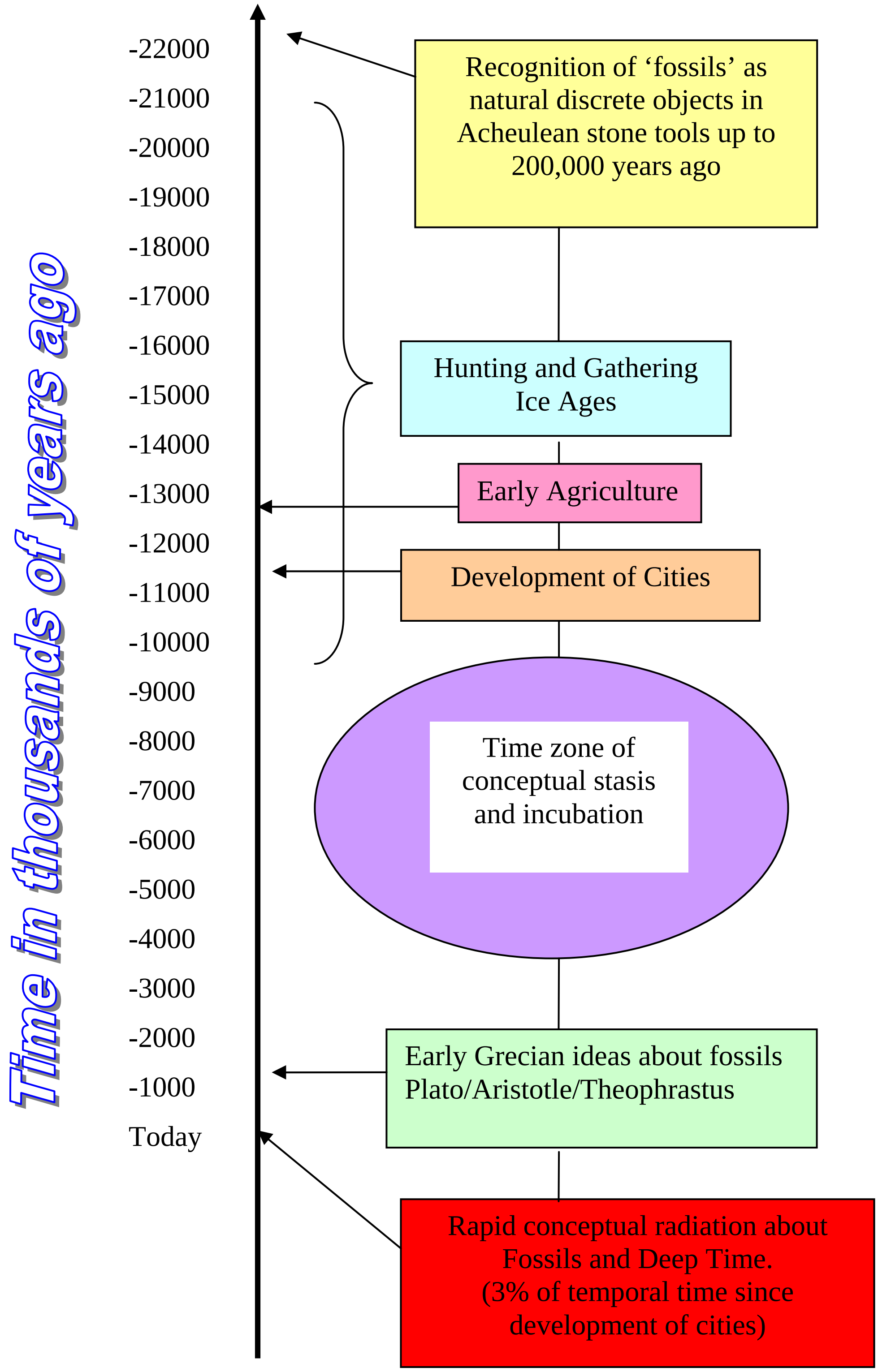


Figure 4.11. Evolution of conceptual change about fossils.

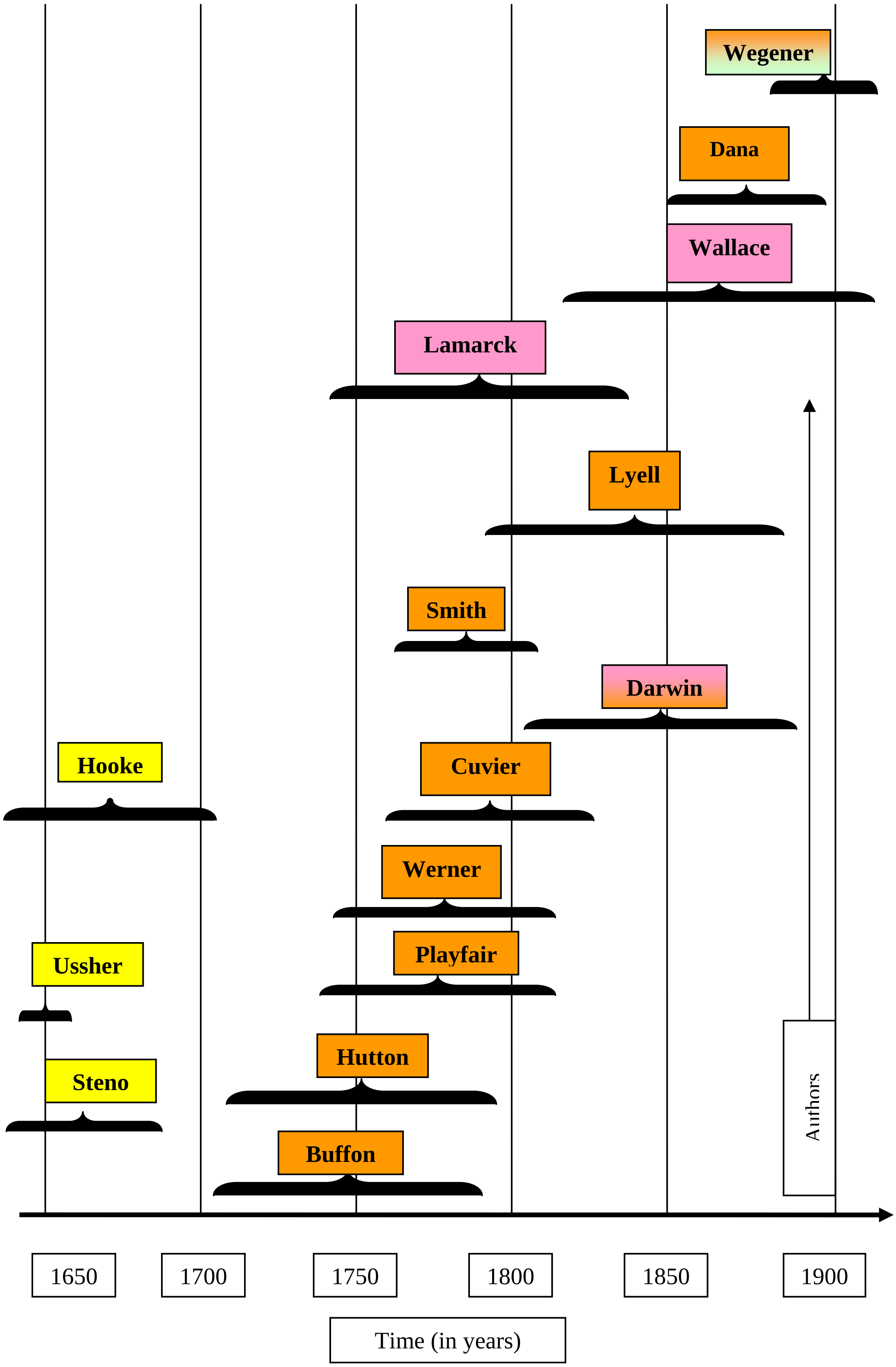


Figure 4.12. Life spans of selected authors for geological time conceptual change.

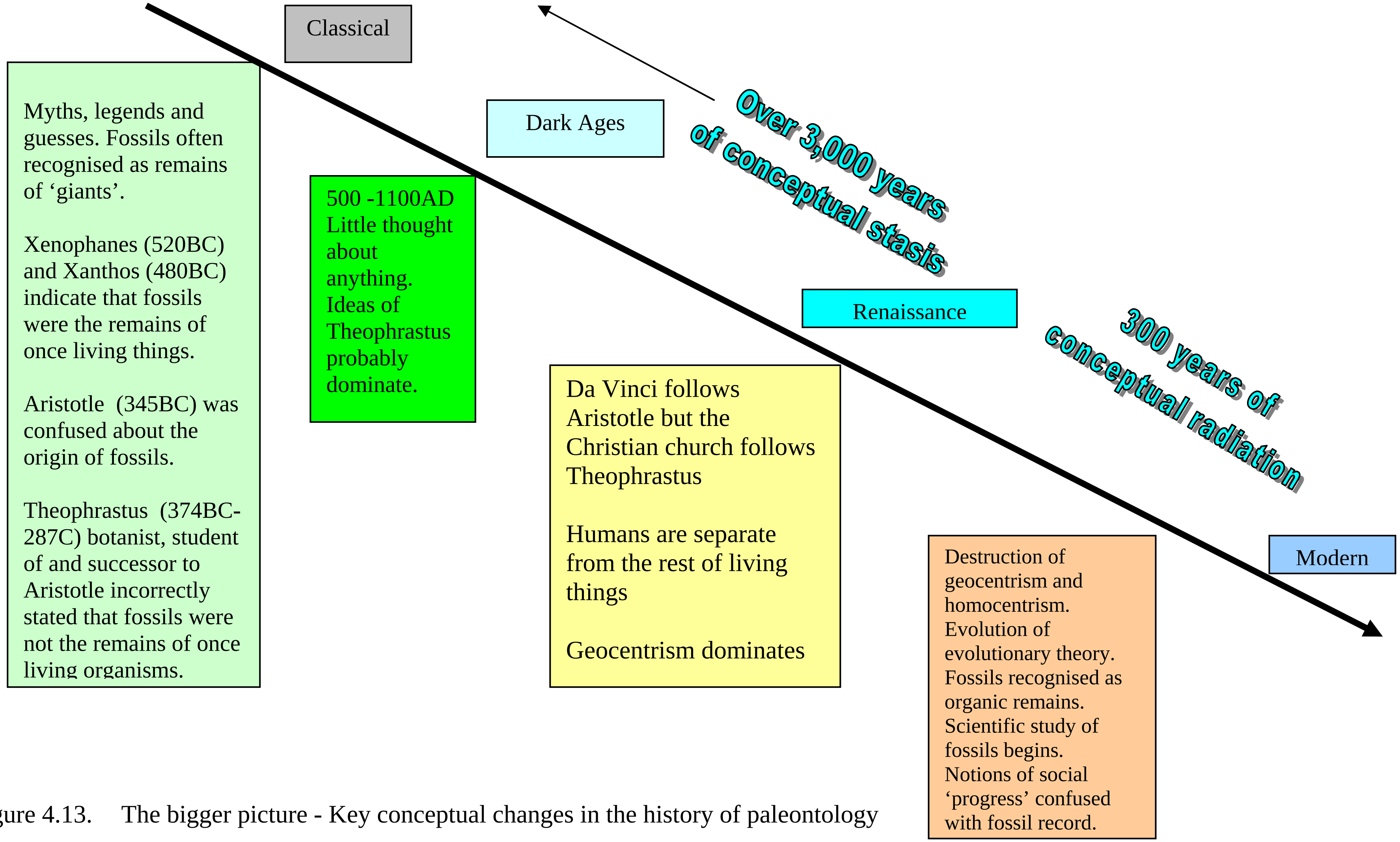


Figure 4.13. The bigger picture - Key conceptual changes in the history of paleontology

4.7 Conceptual Change and the Fossil Record

Despite some classical writers recognising the origin of fossils as the remains of once living organisms (Figure 3.13), it seems odd to us today that it took so long for the truth about the origin of fossils to become accepted. In Frank Dawson Adam's (1958) masterly compilation of the birth and development of the geological sciences he points out some curious concepts that were held about the nature and origin of "figured stones", until that is, one places these concepts within the sociological and religious contexts of the time.

Some common concepts about the origin of fossils held in the Middle Ages (Adams, 1958) suggests that they were considered as:

1. Manifestations of occult powers
2. The force of evil intended to mislead people
3. Irradiations from space
4. Jokes and sports of nature
5. The 'creators' failed and discarded practice attempts at life
6. Spontaneously formed in the earth
7. Formed in the earth from seeds

Some of these concepts (4, 5, 6 and 7) are reviewed in the GeoTSAT concept questionnaire (See Appendix 3) and evidence shows that some, mercifully few of these concepts, are still held by respondents at all ages surveyed (See Chapter 6). The conceptual evolution of the place of fossils in natural history has been much longer in gestation than that for the conceptual evolution of geological time (Figure 4.15). The more abstract and difficult concept of geological time could really only develop after the true nature of fossils was perceived and accepted, and the restrictions of religious dogma were subdued. For this, we have essentially Nicolaus Steno and James Hutton to thank for opening up the concept of deep time. Figure 4.14 shows the place of author life spans in the development of ideas about fossils and the fossil record.

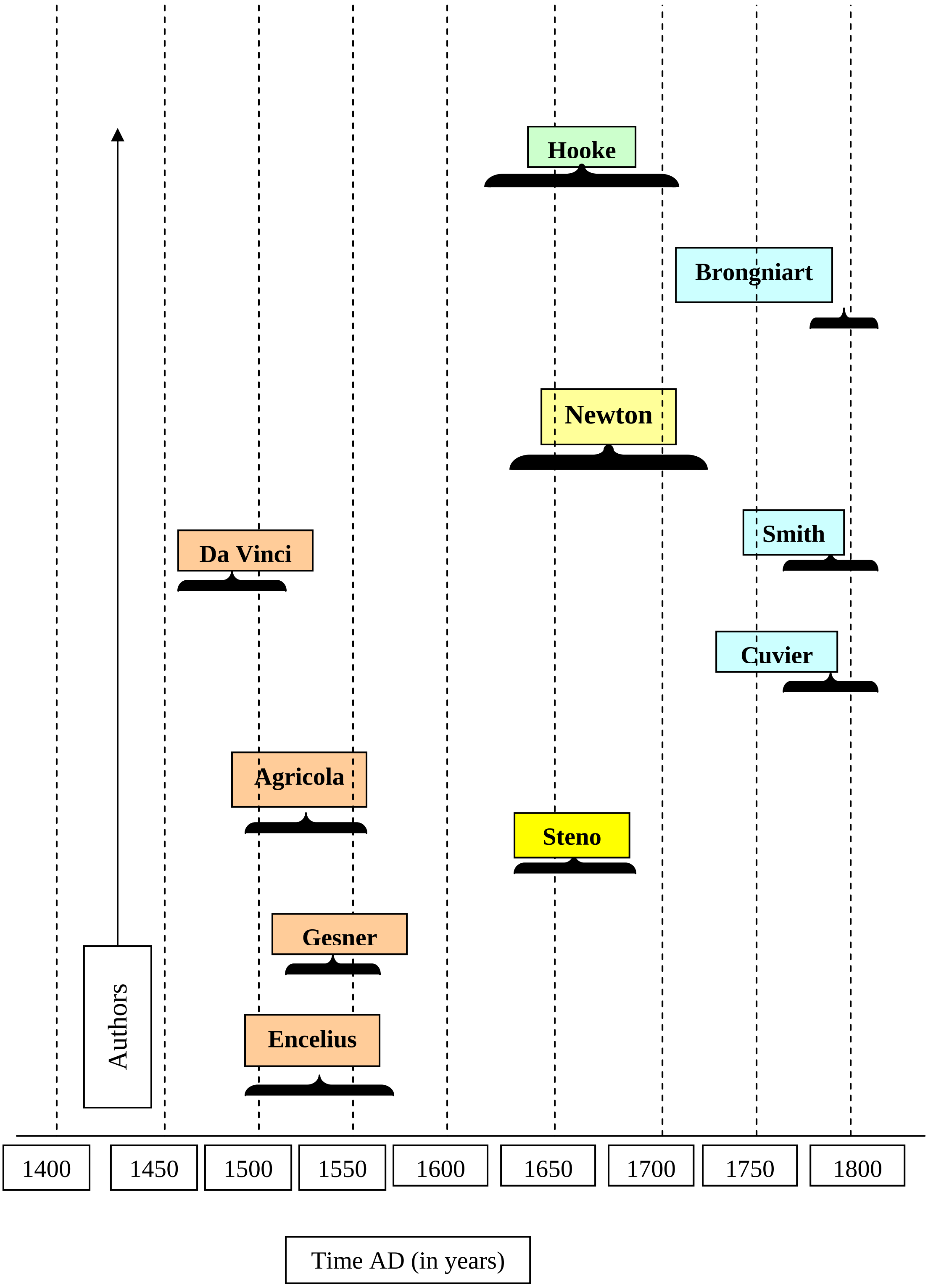


Figure 4.14. Life spans of selected ‘modern’ authors in the history of paleontology

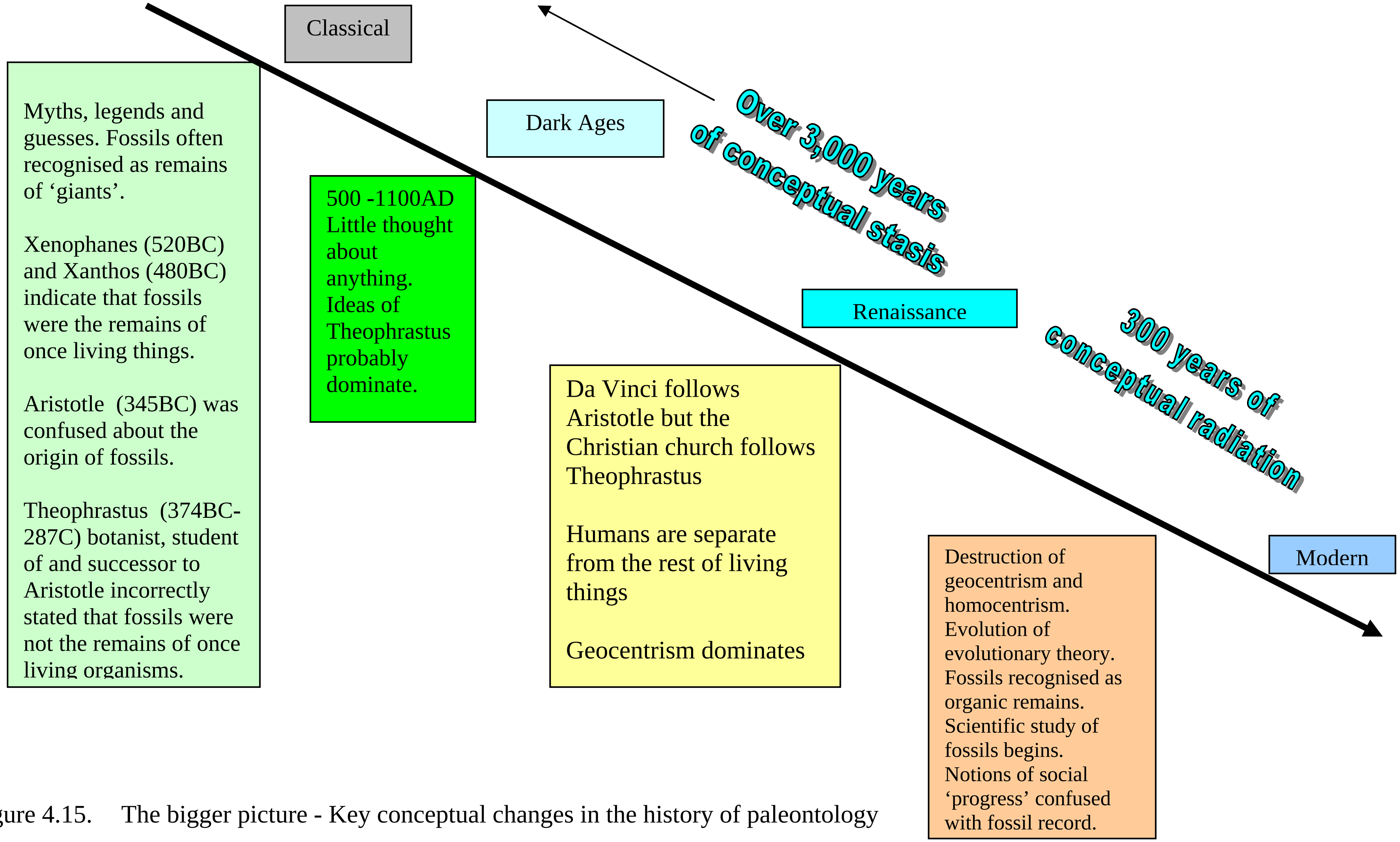


Figure 4.15. The bigger picture - Key conceptual changes in the history of paleontology

4.8 Conceptual Change and the Teacher

Conceptual change theory is an important vehicle for helping to improve teaching and learning. According to Vosniadou (2001b), in the designing of learning environments there must be consideration of the value of learning tasks as well as developing a research-based curriculum. This is easier said and written about than implementing at the classroom level. Unfortunately the gap between grounded and scholarly research based ideas about teaching and learning have a hard time finding their way into the classroom (like much educational research). The reasons for this are complex but essentially it is because of lack of time to implement, lack of connection with curriculum and assessment demands and the accommodation of fruitfulness of research findings. Old traditions die hard! Teachers are wary of validity issues for their individual school variables. Indeed, Duit and Treagust (2003) lament the lack of connection between educational research and teachers and teaching and indeed make the glaring point that to bridge the gap between teachers, teaching and learning, conceptual change theory has to be made more simple (intelligible), and manageable (fruitful). For the earth sciences, Libarkin et al. (2005a), point out the lack of grounded research for college/university age students' (age 18+) conceptualisations, and attempt to begin debate on this issue in their article on college age students' ideas about the Earth. Libarkin also goes on to indicate, that: "Curricular reform efforts should acknowledge the influence of mental perspectives, especially when addressing conceptual change" (*p.25).* This acknowledgement eventually led to the development of the Geology Concept Inventory (GCI) and discussed in section 4.3 as a means of establishing student prior conceptualisation and knowledge understanding of geology, but is yet to be customised for different age groups.

This thesis attempts to address some of these issues as part of a cross-age conceptual change study with particular reference to biological evolution and the fossil record, geological time and geological structures through the lens of visual penetration ability. There is very little point in developing earth science curricula especially via complex systems integration of differing subject concepts (such as Earth Systems Science) which are not cognitively manageable by the learner, and indeed, the teacher. Systems' thinking is a complex cognitive approach to learning that is good for older students but not so good for teenagers.(Ben-Zvi-Assaraf & Orion, 2005).

The speed of social change and the slowness of institutions to respond produce an ever-increasing gap. The 'cold' Posnerian conditions for CC apply also to teachers and these conditions are especially exposed in any curriculum and/or assessment reform. This does not necessarily mean being successful when students' assessments show that they have reached acceptably similar views to 'scientists' views. For teachers, the educational challenge is to provide relevant, motivating and conceptually fruitful opportunities for conceptual learning to happen and the implementation of multi-dimensional aspects in enabling conceptual change may be beyond institutions' and teachers' capacity to handle. Vosniadou and Kollias, (2003) indicate that intentional conceptual change is goal-directed and deliberate and under the control of the learner so assessment necessities may be a hindrance to shifting learner conceptual views.

However, teachers are largely controlled by assessment demands. The problem for teachers is that relatively few students (especially aged 13 to 17 years) are sufficiently motivated and independent for self-directed learning to happen. Thirty six years of classroom teaching tells me that development of socialisation skills dominate thought processes. Science curricula and syllabi dominate a teacher's life and there is tension between covering what a curriculum demands (and attendant accountabilities) and the need to cover what is cognitively accessible by the learner. The balance between curriculum depth and width is also a constant tension for teachers. A key element for teachers is enabling learners to become aware of their own conceptions and perceptions about the world and to help them move from a concrete physical perception to a more abstract model. This process requires learning and teaching time and echoes the difficulty of curriculum breadth versus depth. The theory is fine but the practice is difficult given the realities of a science classroom environment, assessment practicalities and accountabilities. Addressing conceptual development in learners discovering geological time may need the strong connections between the real world outside the classroom from field evidence and the abstraction desired. This development is strongly age related because intellectual capacity changes with age. What appears to be important is that curricula and its delivery must be matched to cognitive levels of learners and have the flexibility to enable teachers to take into account prior learner knowledge and offer appropriate learning opportunities for students to 'safely' change the way they think about the world. The challenge for curriculum reform is to reduce the tension between the needs of teachers to have prescription and the needs of the curriculum to have generic breadth and flexibility.

From a classroom teacher's perspective there is a huge gulf between:

a) Recognition of specific and desirable scientific conceptualisations within key concepts of geology and
b) Being able to develop programmes and teach for enhancing conceptual change but within the manageable realities of the classroom.

Children (and adults) rarely do what the textbooks say they should! Just as assessment is the proxy driver of the curriculum and dynamics of individual student behaviours, attitudes, epistemologies and axiological ecologies group dynamic interactions within an individual class drives the ability of a teacher to implement strategies for the kinds of conceptual changes needed for and individuals 'real' learning. That is, learning where better models for understanding and usefulness are accepted (accommodated?) within an individuals changing scientific world view.

Indeed, the concept of geology as a discipline of study in a curriculum is a global conceptual barrier. For example in the New Zealand experience of curriculum reform of 1994 where geology was introduced as an equal partner to the traditional science subjects, this was accompanied with a howl of protest by teachers who considered this to be an imposition. Similar protests were echoed in the United Kingdom at a similar time (King, 2001). Furthermore, the NZ Science curriculum revisions of 2008-10 continue to provide challenges to the status of geological science in curricula. Old habits die hard, but see Chapter 9 for an update to the NZ curriculum reforms.

> *"….anomalies are often recognized that are inconvenient to a theory, and most scientists are now aware that if the theory cannot ultimately accommodate them, then a new theory will be necessary". (Kelly, L.R., 1997, p.1)*

A recent and important addition to the complexity of conceptual change theory involves that of the notion of threshold concepts (TC) (Carstensen & Bernhard, 2008; Land, 2008; Lucas, 2007; Stokes, King & Libarkin, 2007; Trend, 2009; Truscott, 2006). In essence this invokes the idea of 'transformation' where a key concept in a discipline is pivotal in providing a step to conceptual change. For example, the 'core' concepts of mutation and HO_x genes are critical scaffolding steps for transforming naïve concepts of evolutionary processes into more scientifically acceptable concepts. In a sense, 'threshold concepts' act as triggers for cognitively primed and motivated individuals to explore. The challenge is to find the pedagogic resources that sustainably triggers interest and enables open-mindedness to create actual conceptual change. Trend (2009) outlines a possible way of using threshold concepts and motivational theory to enable conceptual change in learning about geological time (Table 4.3). This schema can be applied to many other geological concepts such as plate tectonics, structures and the rock cycle. This scheme as summarised and modified from Deci, Vallerand, Pelletier and Ryan (1991), Hidi & Renninger, (2006) and Trend (2009) and shows promise for providing 'scaffolded' opportunity for student conceptual change. Unfortunately, the gap between educational research and classroom realities is huge.

Table 4.3. A generalised model for 'threshold concept' pedagogic development.

		Individual Interest Phases			
		Triggered	*Maintained*	*Emerged*	*Developed*
Self Determination	*Autonomous*	Prior knowledge determined. Challenges presented. Starter activities given. Interest ignited. E.g. Pre tuition concept map. DVD. Story telling.	Exposed to and challenged with new and different explanatory concepts of geological phenomena. E.g. Geological environments.	An individual small scale study, inquiry investigation or practical. E.g. Measuring rates of weathering.	Selection of individual role in a class group study. E.g. Recorder of data or trouble shooter.
	Competent	Appropriate activities and tasks are presented to students based on knowledge of differentiated learning styles and age group.	Teacher direction and guidance to ensure acceptable engagement. Depends on age group.	Teacher enables appropriate tasks to be completed.	Self selected tasks with teacher direction, guidance or supervision.
	Socialised	Co-operative, collaborative learning and behaviour activities developed	Liaison with other groups in class	Self selected responsibility for co-operative tasks	Peer presentation of findings organised by group members of a class.

4.9 Chapter Summary

This chapter identifies conceptual change issues that are related to geological education and discusses punctuationism as a model for the evolution of conceptual change theory and uses this to show how key geological science concepts have evolved. Here, conceptual change theory is firmly placed within a timescale. Research question two asks broadly: how do students aged 12 years to graduate develop their conceptions of the fossil record and geological time? This chapter discusses the conceptual evolution of the underlying scientific concepts that students of geology aspire to move to. The chapter discusses the topics of geological time (Deep Time) and the fossil record (paleontology) within a conceptual change framework. Issues of conceptual change as related to the teacher and the learner for geological education were discussed. It is here that the cognitive-situative divide (Vosniadou, 2007) becomes most apparent and that the multi-dimensional nature of conceptual change provides a major challenge for implementation by the teacher in the classroom environment and for the learner in their formative worlds.

This thesis is about geological education and conceptual change. Without an understanding of the evolution of conceptual change theory and its relevance to geological science (by punctuationism, gradualism, ecologically or not at all), having an understanding of why geological science is in the global and local state that it is currently in would not be possible. This chapter attempts to set the theoretical conceptual change framework for geological education within a curriculum and student conceptual context for geological time, history, fossils and geological structures.

CHAPTER FIVE

METHODOLOGY

5.1 Introduction

The purpose of this project is to investigate, define and evaluate aspects of developmental changes in the conceptualisation of key aspects of students' understandings within the earth sciences and specifically, geological science. These aspects also involve student conceptualisation of biological evolution (as embedded in the disciplines of paleontology and paleoenvironments and therefore directly related to geological science), and conceptualisation of geological time as related to geological structures, correlation, and sequencing of geological strata. In addition, aspects of relevant geological science curricula issues are investigated. This work is an attempt to look a little deeper at common conceptions (and misconceptions) as held by students of various ages and within different cultures and curricula. It builds on the work of others and one in which the application of cognitive research to the geological sciences is emerging as of increasing importance. This research effort is grounded within the so called constructivist paradigm where qualitative responses to conceptual probing questions by questionnaire are supported by quantitative analysis to tease out relationships.

5.2 The Research Problem

Cognitive development and understanding of geological processes and histories is dependent on the development of workable (and understandable) conceptions of processes (e.g. systems), time and space. As a historical and often 'pattern seeking' science, geological science demands an understanding and conceptualisation of the immensity of geological time (deep time) and its relativities, and a connected understanding of the evolution of life within this time framework. How individuals develop and express their conceptions of biological evolution, geological time and spatialisation within different cultural and curricular frameworks forms the basis of this research project.

A challenge for educators of geological science (at all levels) is to develop more efficient and relevant ways of teaching geological concepts and move students forward to a more useful and sophisticated understanding. Indeed, there has been a strong call from the international earth science community to improve the role of Earth Science in science curricula (Akhatar, 1996; Cooray, 1996; Mayer, 1997; Stow, 1996.) Data on global curricula (King, 2003, 2008) has been gathered from Europe, South Africa, North America, South America, Eastern, Southern and Western Asia, and Australasia indicating that the call has been slowly answered and variously implemented (See Chapter 3).
As King (2008) points out,

> *A clear imperative is for the evaluation tools devised in some countries to be tested in other regions and curriculum situations, including the Geological Spatial Aptitude Test of Kali and Orion (1996), the Geological Time Aptitude Test of Dodick and Orion (2003b), the Earth Systems thinking tests of Ben-Zvi-Assaraf & Orion (2005), the Outdoor Activity evaluation scale of Vasconceles & Salvador (2003) and the Geoscience Concept Inventory of Libarkin & Anderson (2005) and revised 2008). (p. 26).*

This thesis attempts to build on these beginning geocognitive aspects of geological and geo/earth/ science education and modifies and adapts the GeoTSAT (Kali & Orion, 1996) and GeoTAT (Dodick & Orion, 2003b) instruments in combination with Trend (2001) and Tretter et al. (2006).

The foundational objectives to this study are guided by the following research questions:

Research Question 1

What are the characteristics of international Geoscience curricula and their implementation, with particular case study reference to the New Zealand curriculum?

Research Question 2

How do students aged between 12 and 40 develop their conceptions of evolution and the fossil record, geological time and 3-D geological structures?

Research Question 3

What is the influence of diachronic thinking on conceptions of geological time, structures and fossils?

Research Question 4

What is the influence of visual/spatialisation on conceptions of geological structures?

Research Question 5

How do conceptualisations of fossils, geological time and geological structures vary with age of respondent?

In effect, these research questions ask about the relationships and baseline conceptions of students of different ages and backgrounds in their understanding of fossils and the fossil record (and its relationship to biological evolution), elucidating geological histories and spatialisation reasoning for geological structures. This research effort is grounded in a constructivist perspective for conceptual status and change within a geological science context.

5.3 Methodology

This thesis sets out to investigate key aspects of geological science education within a constructivist and conceptual change framework. Specific aspects of geology involve geological time, geospatialisation, concepts of evolution and the fossil record, and curriculum and assessment issues. A constructivist paradigm (Anderson & Arsenault, 2001; Guba & Lincoln, 1994; Patton, 1990) essentially informs and controls the methods that are used to investigate the research questions (See Section 5.2).

> "Constructivism …aims at understanding and reconstructing knowledge with the goal of moving consensus and more informed ways of knowing".
> (Anderson & Arsenault, p. 120).

These aspects thus involve a positivistic and grounded theory approach to gather information about the conceptual development of a cross age sample of respondents through pre validated and modified questionnaires as well as by case study.

Conceptual change theory provides the grounded framework for positivistic interpretation of data. In line with Patton's common sense approach to research paradigms, the breadth of research questions addressed in this thesis demands a mixed set of methods that will enable valid and reliable data gathering for meaningful interpretation. Interpretations of data, as informed by conceptual change theory, is viewed in this thesis from a multidimensional point of view (Tyson et al, 1997) and as defined by Duit and Treagust (2003), conceptual change refers to the processes of the reconstruction of learning pathways which enable students to form more sophisticated scientific explanations of scientific phenomena but in this case, geological phenomena. In effect this means making meaningful learning changes to the way individuals think through research based teaching.

In essence then, this is a mixed method study involving quantitative analysis, qualitative unstructured interview questioning, structured and pre-validated questionnaires, as well as the use of secondary source analyses. A case study approach is also used (Chapter 9) to provide a more detailed and specific study of aspects of geological science education in the New Zealand Science curriculum with special reference to the 2008-2010 reforms. This case study has stretched over several years.

5.4 Methods

Figure 5.1 summarises the methods used for data gathering to inform curriculum and geological conceptualisation issues. Limited information via secondary source surveys such as the 2003 and 2006 International Geoscience Education Organisation (IGEO) surveys are currently available for describing a general picture of the global status of general geoscience (and its major sub discipline of geology). The 2010 IGEO conference in Johannesburg will ideally provide an update on the global status. Similarly, secondary source information is equally difficult to obtain for current New Zealand curriculum reform issues as associated with changes in the geoscience and geological science assessment standards and curriculum. A postscript in Chapter 9 and data presentation in Appendix 8 describes the most up to date curriculum reforms available. Literature availability is often buried in unpublished departmental reports and requires considerable bureaucracy via the Official Information Act, 1982, to extract. Data may be well out of date before receipt.

The only way of gathering information from other countries was to use questionnaires. For the Israeli sample, questions were translated into Hebrew and some written answers were translated back into English. Questionnaires were designed for minimal written answer responses and the spatialisation tasks do not require this: they require block diagram completion. For the Lebanese samples, students were fluent in English and translation was not required.

Typically, questionnaires are efficient and valid means of collecting data. However, they do suffer from issues of return rates, ‘saboteurs’ and reliability much of this can be overcome by careful construction and trialling. The use of pre validated questionnaires for GeoTSAT and GeoVAT enhanced trustworthiness.

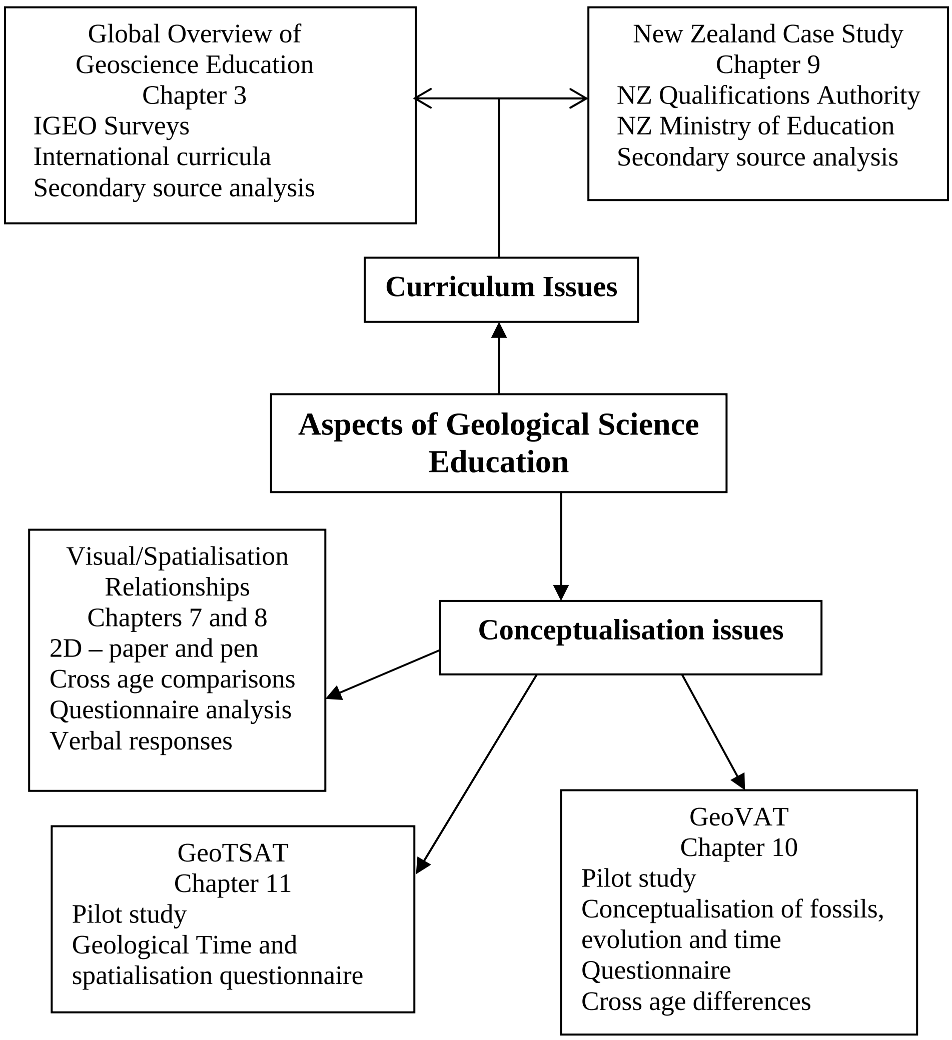


Figure 5.1. Key conceptual elements of methodology

5.5 Data Collection

Table 5.1 summarises the instrumentation and analytical methods for the research questions and Table 5.2 shows the respondent country sources and Table 5.3 shows a summary of students' sample ages. Triangulation with historical data and individual interviews enhances reliability and in particular, enables a detailed analysis of student thinking on visual penetration abilities and their conceptions of 'Deep Time' and the role of fossils in their conceptualisations of geological history.

Table 5.1. Summary of instruments used

Research Question	Instrument	Type of Data	Data Analysis
1	Secondary data sources	Quantitative	Narrative, means analysis and clustering
2	Geol time and spatial aptitude test (GeoTSAT) and the Geol evolution aptitude (GeoVAT) test.	Qualitative and quantitative	Semi structured interviews, questionnaires, ANOVA, multivariate clustering
3	GeoTSAT, GeoVAT	Qualitative and quantitative	Multivariate clustering. SimStat: Internal consistency reliability analysis. Narrative
4	GeoTSAT, GeoVAT	Qualitative and quantitative	Narrative and correlations
5	GeoTSAT and GeoVAT	Qualitative and quantitative	Unstructured interviews, questionnaires, ANOVA, multivariate clustering.

Table 5.2. Country data sources

Country Source	Respondent Ages (Years)	Comment
New Zealand (AC) (UC)	13 - 30	The author's secondary school Univ. Canterbury Teacher Training College and Geological Sciences Department
Lebanon (AUB)	19 - 24	English speaking primary and secondary teacher trainees
Israel (IS)	14 - 18	Co-ordinator's kibbutz school near Eilat

Table 5.3. Summary of respondent samples.

Student Sample	Mean Age	Mean n
AUB Lebanon Secondary teacher trainees	22	9
AUB Lebanon Primary teacher trainees	19	9
UC (NZ) Secondary teacher trainees	27	9
UC Postgraduate geology students	27	10
UC Year 3 geology students	22	15
UC Year 2 geology students	21	9
UC Year 1 geology students	20	24
AC (NZ) Year 13 students	18	23
AC Year 12 students	17	13
AC Year 11 students	15	13
AC Year 10 students	14	12
AC Year 9 students	13	13
TOTAL (N)		150

Note that respondent numbers vary from question to question and cohort to cohort.

5.6 GeoTSAT (*Geo*logical *T*ime and *S*patial *A*ptitude *T*est) Validation

The decision to use a pre validated questionnaire instrument was deliberate. Why reinvent the wheel? In Jonathan Osborne's dinner speech at the NARST conference (2007) as outgoing president, he stated:

> *Basically, I want to make a case for a bit more armchair science education research. What I mean by that is epitomised for me by a student question to a colleague who is an educational psychologist – Guy Claxton – who had just given a seminar. If you have never read any of his writings or heard him speak then I would commend him to you. The strange thing about Guy Claxton is that he is an educational psychologist who has never collected one piece of data. At the end of a seminar, this student had the temerity to say – 'What you have just been talking about is really interesting – tell me, have you ever collected any data on that?' What was Guy's response? 'Good God no, there is enough data out there in the world without me going out there and collecting any more". (p.5)* and,

> *Are we as a community rushing to undertake empirical work when more time spent ferreting out secondary data [and] critically examining the theoretical ideas that guide our work might be more useful? (p. 7).*

Dodick and Orion (2003c) validated the original GeoTAT instrument (and subsequently modified for use in this thesis as GeoTSAT) for construct validation, content validation and question validation with the final version being administered in 1992-2000 to a total of 285 grade 7-12 students (Age 12-18 years). This in turn was based on the earlier work of Kali (1993) and Kali & Orion (1996). The development of this questionnaire instrument was in turn based on the earlier work of Gardner (1975), Koballa (1984) and Orion and Hofstein (1991). Statistical comparative analysis was carried out using principal factor with varimax rotation and Cronbach analysis which tested for internal consistency and reliability of the questions after pre-testing.

Geospatial abilities were tested using 3-D block diagrams in the GeoTSAT instrument. These diagrams are in effect ‘completion’ tests where students are required to use their geospatial abilities (especially visual penetration ability) to complete the continuation of strata onto one or more sides of a block diagram. Details of each completion test for the GeoTSAT instrument is outlined in Chapter 7. Testing geospatial ability to translate a plan view into a cross sectional view was tested for in the GeoVAT instrument.

The GeoVAT and GeoTSAT content (appendices 2 and 5) were validated for use by expert review and in particular, review by Professor Jacque Montangero to validate the fit of questions for cognitive diachronic thinking. In other words, the questions were validated for content that would enable the testing of diachronic thinking within a geological science context. The use of a non-geological puzzle for internal triangulation was not included in this thesis questionnaire (GeoTSAT) as there was no intention to investigate the impact of geological training on conceptual status. Pre-testing of 116 Israeli grade 10 non geology students and 21 geology students was carried out to moderate for ambiguity, difficulty and response times. The original instrument was completed in 45 minutes and for this thesis, up to one hour was recommended. Providing this time for completion was out of the researchers control and may well be a significant limiting factor in provision of a larger sample size. Teachers and co-ordinators are busy people and questionnaire completion is an intrusion on tuition time as well as being perceived by respondents as taking time away from their studies. Prior learning in biology or geology was not considered for investigation in this thesis, so the effect of this variable is unknown and deserves further investigation and control. In essence, the GeoTSAT questionnaire (See appendix 2) gathers some demographic data and cross references the testing of conceptualisation of relative time and comprehension and application of the laws of superposition. It also provides information about a range of visual/spatialisation skills (Linn & Peterson, 1985) and across different ages. In particular, rotation and visual penetration ability (VPA) is investigated using a variety of pen and paper 3-D exercises and 'hands on' plasticine models. Visual penetration ability as related to geological structure was first investigated by Kali (1993), Kali and Orion (1993; 1996; Orion, 1997a) and (Orion, 1994; Orion, 1997a, 1997b). Kali and Orion's work was also pilot tested on 64 Israeli fifteen year olds and statistically validated (Kali & Orion, 1996). Prior to this, most visual/spatialisation educational research was concerned with chemical molecular structures and geometry and not the geological sciences (Bishop, 1980; Mitchelmore, 1980; Mundy, 1987). A concise literature review of visual spatialisation research is outlined in Kali & Orion (1996). However, Kali and Orion used pen and paper exercises and not a 'hands on' 3-D model as developed for this thesis work on visual penetration ability (VPA). The decision to use a plasticine model for investigating visual penetration ability (VPA) was an attempt to enhance the pen and paper exercises developed for the GeoTSAT and GeoVAT instruments and to allow learners to touch and visually see the 3-D version of the pen and pencil block diagrams. The results and details of this investigation are outlined in Chapter 8.

5.7 Data Analysis

Statistical analysis involved the use of multivariate statistical programming (MVSP) clustering (Kovach, 1998) and ANOVA. MVSP clustering is a statistical package with a variety of possible techniques. In this thesis, a minimum variance (sum of squares cluster using Ward's method) hierarchical technique was selected to provide clusters based on how much variation there is within each cluster for selected variables. In successive rounds of clustering, selection is based on which two factors would provide the least increase in within-cluster variation. In this way, a parsimonious dendrogram (A 'similarity' tree diagram showing relationships of clustered variables) is produced. Multivariate clustering analysis enables data to be looked at from different perspectives which include multiple variables that are common to all samples. As an example, the use of multivariate clustering analysis clusters the percentage of statements relating 'geology' as the solid earth component within Science curricula from each country. This enables a measure of statistical similarities to be made where countries can be grouped into countries with the greatest similarity of data.. Clustering of countries into similarity groups enables new perspectives to be found and new questions to be asked.

ANOVA was used to investigate and determine variation in responses to the GeoVAT and GeoTSAT questionnaires. Interpretations of data and qualitative information are based on generally accepted scientific conceptualisations as expressed in peer reviewed publications.

An initial pilot study given to NZ Year 11 students for question construct validity issues was carried out and some of these results are included in the AC Year 11 findings.

Cronbach's Alpha statistic for internal consistency of cohort responses for specific questions of the GeoVAT and GeoTSAT questionnaires was completed with the use of SimStat statistical programme (Peledeau, 1996). Table 5.4 shows the results of this analysis. These results indicate that student responses to questions in both the GeoVAT and GeoTSAT instruments are reliable and validate conclusions based on the student responses.

Table 5.4. Summary statistics of response reliability.

	GeoTSAT Q's 7a, 7b, 7c, 7d, 8a(i), 8a(ii), 8b, 8c.	GeoVAT Q1	GeoVAT Q3
Mean Inter-item correlation	0.45	0.42	0.55
Cronbach's alpha	0.85	0.93	0.97
Standardised item alpha	0.85	0.93	0.97
Valid cases	111	208	115

5.8 GeoVAT (***Geo***logical E***v***olution ***A***ptitude ***T***est) Questionnaire Validation

This adapted and modified questionnaire (See Appendix 5) is based on instruments trialled (albeit on a relatively small sample) and implemented by Trend (1998; 2000;

2001a), Tretter (2006), Dodick, and Orion (2000b; 2003a; 2003c) and Dodick (2007). Section A of the GeoTSAT instrument investigates the dichotomous student true/false conceptual ideas about fossils, the fossil record and the nature of science. These true/false responses were 'teased out' in further questions by asking for explanation. These dichotomous responses enabled the gathering of unambiguous information of student conceptualisation about fossils. It also enabled the identification of those students with confused and antagonistic views of evolution. Questions were asked about the geological usefulness of fossils in an evolutionary and stratigraphic (relative geological time) context and so triangulates somewhat with the GeoTSAT instrument. Section B question 2a also tests students ability to visually rotate a plane map area into a cross section and triangulates with questions 6 and 7 from the GeoTSAT instrument on geological structures. Other questions (Section B, question 2c) attempts to probe conceptions held about the linkages between geological environments and the fossil record (after Dodick & Orion). These environments are further investigated with Section B question 2d on a 'look and sound like' perception of the early Earth and today. Section B, question 3a is an adaptation and modification of that originally used by Trend (2001) and asks for students to place geological events into a time frame. Later work by Tretter et al. (2006) (also founded on Trend's 2001 study) and Jones, Tretter, Taylor and Oppewal (2008) was adapted and used to investigate conceptual status and applications of scale to geological contexts. Findings in this thesis are spread across an age range of 13 to graduate geologists, primary and secondary school teacher trainees from New Zealand and Lebanon, and also across a range of secondary school classes from New Zealand and Israel. High school student ages ranged from 13 to 18 years.

5.9 Trustworthiness and Limitations

An investigation's trust depends on reliability and validity of collected data. Embedded in this are notions of demonstrable credibility and ethically obtained information. Similarly, instruments are not valid unless they are reliable and constrained to their purpose. Questionnaires are good and bad for providing information. For example, in the dichotomous true/false question of Section A, students are forced to make decisions on their ideas about fossils, the fossil record, the nature of science, and styles of rates of change for biological evolution. Keeping in mind the maxim ‘garbage-in-garbage out’, questionnaires also enable a degree of quantitative analysis. To improve trustworthiness and provide an internal cross referencing triangulation, students were then asked to **explain** any two of their decisions which they thought were true. This for example revealed again, the well established notion that many students still do not (or cannot) separate the **scientific** aspects from the word ‘**theory’** when related to biological evolution.

The key limitation in data gathering for this thesis (without the resources of the OECD for example) was an inability to obtain large samples with complete sets of answers. Once questionnaires are handed over to co-ordinators in another country, there is a loss management control. It is typical that few responders have complete papers, and there is reliance (like the fossil record) on making inferences based on skewed, incomplete and biased samples but nevertheless, evidence. In the end, one goes with the data that one gets, and it is impossible to ‘redo’ data gathering unless there is an unlimited time frame.

This study does not use statistical analyses of questionnaires to generate statistically representative conclusions; rather, it uses gathered information to provide insights and snapshots of the conceptual and perceptual status of a wide age range of responders in a geological science context. Guba and Lincoln (1989) consider trustworthiness in a qualitative gathering of information as referring to the general ‘quality’ of a piece of research and involves findings and conclusions that are transferable, dependable, credible and confirmable. The methodology and findings in this thesis are based on these notions. Findings in this thesis are transferable in the sense that they are open to scrutiny, application and replication in a validly similar educational environment. Small sample size for statistical analysis is always an issue however, this is also ameliorated by the limited responses to validated questions.

5.10 Ethical Issues

Like all research, ethical behaviour and data management with informed consent and protection of privacy is essential to provide trust in data gathering and results. This thesis research did not require identification of individuals nor specific institutions but does identify origin countries of data sources, as this provides the basis for curricula and cultural parameters which influence conceptualisations. All data and information gathering from people is an intrusion and as Steven Pinker (Pinker, 2002) has pointed out, there is no such thing as a 'blank slate': people come with their nurtured and genetic ontologies and world views. So does the reader of this thesis. This research effort is about investigating further, **geological** conceptualisations held by students of a wide age range and not about intruding and prying on individual belief systems. It is the conceptualisations (and misconceptions) that count, rather than *where* the ideas come from, except that a respondent's geographic locality is just one of the many ontological and axiological factors that influence the development of geological conceptions. This is an issue of investigation for this thesis. For example Lebanon is predominantly a Muslim culture, Israel a Judaic culture and New Zealand predominantly secular. Culture influences curricula which in turn influences teacher training which in turn influences teaching and learning.

All participants (Co-ordinators and respondents) in data gathering were informed in writing of the purpose of the questionnaires and were free to choose anonymously of their participation. In the researchers own school, colleagues were willing participants in administration of questionnaires. Because information is anonymous (apart from country of origin and institution) confidentiality is not an issue. The focus is on gathering information about ontological conceptualisation of geological science. Along with return rates and completion rates, accountability is an important issue in questionnaire data gathering. The researcher is transparently accountable for the protocols and gathering of information through audit trails (Anderson, 2001), but the respondents are free to respond to questions in any way they want. This is despite suggestions requesting honesty in answering. Most respondents will therefore just answer the questions they want to answer in any way they want with no way of ensuring respondents be accountable for their decisions. In short, the ethical behaviour of a respondent is critical for reliability of data but this is often overlooked as being largely unmanageable. Reliability of responses is therefore left to be managed and mitigated by internal cross referencing of questions and triangulation of data sources. The researcher has to make decisions on inclusion and exclusion of data and is left to make sense of a distribution of responses from the honest and engaged, the dishonest and disengaged and the ignorant to the informed. A holistic view point of individual responses was used in this thesis data collection.

All recorded data remain confidential and anonymous for five years and stored in a secure electronic form (CD-ROM/Key Drive and in pdf format). All respondents are volunteers and ethical cognisance of individual and collective rights were respected. Ethical committee forms for questionnaires have been completed and approved with cultural sensitivity and protocols being observed where required.

5.11 Chapter Summary

This chapter describes the theoretical basis, research questions, methodology and methods used in this thesis. Perfection does not exist and especially so from any data and information gathering instrument where human responses are required. Trustworthiness of findings is therefore based on the degree of validity and reliability of responses generated from questionnaire construction, quantitative support, subject content and ‘readability’ by respondents. Internal consistency and triangulation is ‘built-in’ and validated instruments are employed. Results data are internally statistically consistent and reliable (See statistics in Appendix 8). Universally representative conclusions from data collection about geological conceptual status are not professed, but this thesis attempts to replicate (with some modification), enhance and discover new ideas and support old ones through valid and reliable instruments with cognisance to the ethics involved. Findings from across a wide age range and with some social cultural independence enhances reliability, decreases cultural bias and gets a little closer to respondents’ conceptions of geological time, geospatialisation and biological evolution.

CHAPTER SIX

ABOUT TIME

6.1 Introduction

> *Time continues to attract considerable attention from authors writing from a wide range of perspectives, but rarely do educational researchers address geological time* (Trend, 2000. p.539).

Geological time is a cornerstone concept of the geological sciences and without an understanding of this dimension nothing in the natural world makes a lot of sense. This chapter addresses aspects of research question 3: *What is the influence of diachronic thinking on conceptions of geological time, structures and fossils?* Developing a diachronic sense of time and its application to geological phenomena is a perquisite conceptualisation for geological processes and products.

From infinity to attoseconds and billions of years, scales of time are difficult to comprehend. Not only is the perception of time fundamental to our conceptions of space and geology but also to our daily lives. Indeed, with the brains biochemical seat of time perception now reasonably identified as in the basal ganglia of the brain (Driesen, 2001; Meck, 2005), the perception of time is implicated in the time twisted behavioural displays seen with people diagnosed with Attention Deficit and Hyperactivity Disorder (ADHD), Attention Deficit Disorder (ADD) and Parkinson's disease. Certainly, when personally observing students in a science class who have been authentically diagnosed as having ADD and/or ADHD, their abnormally mismatched adolescent perceptions of time durations and task completion expectations becomes very clear.

In Damasio's article (2006), in which he discusses the brain structures that are involved in piecing together and remembering our experiences of time, investigations with brain damaged individuals suggest that the hippocampus and the temporal lobes on the sides of our head are directly implicated in how time relative memories are constructed. Events are placed in time order by this part of the brain along with a scale of relativity (Damasio, 2006). This "mind time" has implications for the way we develop (or not) our conceptualisations of geological Deep-Time, and indeed, the way in which we ‘read’ and perceive the rock record at a physical rock outcrop on the side of a local road or when we gaze over the edge of the Grand Canyon or wonder at the karst topography surrounding Guilin in China.

From a social point of view, Waugh (1999) suggests that in the Christian faith, God invented our universal time, this, despite the fact that different cultures have different social perceptions and values of time. For example, the ‘Dreamtime’ of Australian Aboriginals is quite different to that of the Muslim Wahabinist sect where apparently, the past is always carried with the present. However, the first verse of the biblical Genesis story was discovered (in a cuneiform tablet in the 1870’s, near Mosul in Iraq) to have been a myth copied by the Jews of an even earlier Chaldean account of ‘origins’ about 700 BC. Agriculture and cities had evolved and appeared about nine thousand years before this (See Chapter 4, Figure 4.11) so creation myths (and questions about time) have been around for a very long time (relativistically and durationally). Creation myths and legends all attempt to account for whether time had a beginning or not but all scientifically fail because they require unmeasurable and untestable acts of faith.

Earth scientists and geologists today have become conditioned into thinking in millions and billions of years. The ‘billions’ of years is of course that much more difficult to perceive and conceptualise although as Ault (1981) has shown in his study of children’s conceptions of time and geological time, their conceptions do not appear to act as a barrier to their understanding of geological time. As has been shown by Trend (1997; 2000; 2001a), young students aged 11 years, young adults aged 17 years and primary teacher trainees tend to lump their understandings of geological time into blocks of time from extremely ancient to less ancient and finally to modern. This chapter looks at how students of different ages develop their concepts of geological time and the unique place geological time has to teaching and learning in the earth sciences. Trend’s (2002) study has been adopted, adapted and used in the GeoVAT instrument (Section B, question 3) as a basis for teasing out some of these ‘deep time’ conceptions and perceptions held by students of different ages.

6.2 An Illustrative Study for Scales of Time, Size and Mass

Based on availability of respondents and a reasonable age and 'learning' gap, a class of New Zealand rural high school 13 year olds (n =22) and 16 year olds (n =24) were asked in a minimally directed way to write descriptions in their own words of how they would describe their perceptions of scales of time, size and number. Results are presented below. The number of responses is in brackets.

6.2.1 New Zealand Thirteen Year Old Student Responses

Out of 22 responses, three were minimal responses but indicated that these students did have a concept of scale. For one of these minimal responses, the only written response for a time scale was "a minute ago", as if to simply say that they recognised past and present (the now) but the future was not recorded. For size, this student indicated a "t –rex" as the largest size they could conceptualise. On the other hand, perhaps limitations of written language expression and lack of intent precluded further explanation? These invalid responses may also indicate what Montangero (1996, p. 29) calls "the gulf which can divide recognitive knowledge or knowledge which can be activated on request, from spontaneously evoked knowledge". In other words, these students had the knowledge but did not want to say.

Most responses indicated time as stretching from seconds to millennia and only one recognised a geological deep time of a million years as the largest unit of time in their scale. The number of respondents was 22 with 5 'did not attempts'. When gently asked as to why they had not responded, the common answer was concerned with a lack of ability and confidence to express in words what they thought. In other words, a literacy difficulty. Being able to express ideas in a meaningful way is a common problem which can sometimes be overcome by verbal descriptions. Two of the 'did not attempt' students could not be bothered. There was insufficient time to pursue this issue with providing these students with the opportunity to verbalise their thoughts.

Table 6.1. Student responses to **time** scale order (Not selected from any list)

Number of respondents (n = 17)	Time scale order Responses
10	*Millenniums, century, decades, years, months, days, hours, minutes, seconds, milliseconds*
2	*Millennia, century, year, month, second, minutes, hours*
1	*Millennium, seconds*
1	*Millisecond, hour*
1	*The smallest time I can think of is 0.0001 and the oldest time I can think of is 1 million years*
1	*Old people, young people*
1	*O'clock, year, half past, quarter past, 10 past, 5 past, 1 past, seconds, milliseconds*
1	*One minute ago*

Table 6.1 shows student descriptions of a **time scale** ordering of events. It is likely that students perceive the 'boundary' gap between 'their' millennia (which they saw as thousands of years), and seconds, as their 'distance' gap. It seems that their experiences do not allow them to reach out beyond the millennia of the past and they probably see millennia as stretching into the past and the future. For these students, geological time is not within their experiences and so all unimaginable time is lumped together as "millennia" or as in one case, connected with 'dinosaurs'.

Table 6.2. Student responses to **size** scale boundaries (not selected from a list)

Number of Respondents (n =15)	Size Scale 'Boundary'
4	*Extra small, small, medium, large, XL, XXL, XXXL, XXXXL*
2	*Small, large*
2	*Milligram, tonne*
2	*The smallest size is 1cm the biggest size is I million kilometres*
2	*Little, small, tiny, big, huge, giant, gargantuan, King Kong*
1	*Millimetre, kilometre*
1	*Small, big, huge*
1	*King Kong, bugs*

Size scale descriptions (Tables 6.2 and 6.3) were dominantly relative to human body size as most responses used the size of clothing that a person could get into as their reference category. Small, big and huge seemed to have some meaning for many others. Others used the biggest animal and smallest animal they knew as their reference point with no one using shrubs and trees as their reference category. Still others used a dichotomous scale of "small and large" with one trying to 'fill in the gap' with small, big and huge. Two respondents confused mass with size.

Table. 6.3. 'Free' responses to number scale boundaries (n = 14)

Zero to infinity (1 respondent)
1, 2, 3…… (1)
The smallest number is 1, the biggest is 1000000000000… (3)
Infinity,1 billion, 10 billion, 100 billion, 1 trillion, 10 trillion, infinity(1)
Zero to 100 (3)
1 to infinity (2)
1 to 999999999 (1)
Largest is infinity, middle is one hundred and fifty and smallest is 0.1 (1)
Infinity, zero, infinity (1)

In this class sample, the idea that numbers start at zero or one or multiples thereof is encapsulated. The concept of negative (below zero) as being part of their number perception and conception scale has not yet developed in these 13 year olds. Perhaps this is why this age student has so much trouble conceptualising below zero temperatures or older than 'now' time or smaller than a millimetre in size. So conceptualising atoms (and parts of atoms) along with conceptualising geological time is likely to be cognitively beyond these students until their personal and educational experiences teaches them otherwise. Many students do not stay in educational systems long enough for these experiences to mature. It is also interesting that in Tretter's et al. (2006) study, high school students categorise or lump "textbook to atom size" objects into the "small" (See Appendix 4). This is analogous to students' lumping geological time events into Trend's "extremely ancient" category. Elementary school aged students do the same but include "me" as a reference point. As age increases, refinement of size subdivision increases in sophistication. In effect, the relative 'intrascale' and 'interscale' boundaries of time and distance are expanded with experiences and age. This illustrative study lends support to this supposition with senior high school students refining their scale boundaries. For conceptualising geological time, students need to be exposed to experiences of fossil lineages, stratigraphic columns, ice cores and radiometric dating and all within a real world outdoor context.

6.2.2 New Zealand Sixteen Year Old Student Responses

These students have the advantage of an additional three years learning experiences and their responses generally reflect this. Are their scale boundaries of time, size and distance significantly different to younger students? Their responses are recorded in Tables 6.4, 6.5 and 6.6. The number of respondents was 11.

Overall, it was interesting that these students tended to dichotomise their responses into two large categories rather than to divide into the minutiae, as if there was some kind of recognition that mental scale boundaries are more complicated than at first glance. Class discussion after collection of ideas indicated that this group of older students did not so readily place the human body as the first reference point in their scale for size, but many did use their own age as a beginning reference point for **their** time scale. For some, time only began from their own birth. Most considered the 'Big Bang' to be the beginning of everything although one student thought there was a need for a little time before the 'Big Bang' in order to get ready for it. Junior students had not yet been seriously exposed to the concept of the 'Big Bang'. Future research on student conceptual evolution of ideas about the origin of the universe may shed light on how scalar perceptions are developed and applied to scientific explanations. Another student considered that everything before the birth of Christ (a dominantly Christian group) should be lumped together and that anything beyond a thousand years into the future was too difficult to comprehend and should therefore be lumped together as "the future". Although recognised as eons or millions of years, geological time did not appear to be connected with any geological events that mark Earth history. This aspect is investigated and discussed more fully in Chapter 11. Geological 'Deep-Time is beyond their experiences. Indeed, 'thinking in time' and ‘explaining in time’ adds a new dimension to our knowledge of beings and things’. (Montangero, 1996, p. 12).

Table 6.4. Sixteen year old responses to **Time** scale boundaries (n = 11).

Seconds to thousands of years (1 respondent)
Minutes to centuries millions of years back to decades in the future(1)
Big Bang, forever but a little time before the Big Bang (1)
Milliseconds to Eons (1)
Before Christ to infinity. Everything BC is lumped together and all the future is lumped together after 1000 years (2)
Milliseconds to millenniums (2)
No time, nothing, to 100th’s of a second to centuries (1)
Sixteen years in the past to fifteen years in the future (1)
From my age 16 and up (1)

Table 6.5. Sixteen year old responses to **Size** scale boundaries (n = 11).

1cm to 2m (1 respondent)
1cm to about dinosaur size (1)
Milligrams to tonnes (1)
Millimetres to kilometres (1)
Sub atomic to universal (1)
1m to hundreds of kilometres(1)
Microscopic to unobservable (2)
Centimetres to kilometres, atom to planet (1)
1cm to 1000cm (1)

Table. 6.6. Sixteen year old responses to **Number** scale boundaries (n =11).

1-100 (2 respondents)
1 to one hundred thousand (1)
One to millions (1)
Infinity (1)
1 to ten(1)
0 to infinity(3)
Negative infinity to infinity (1)
1 to 1000 (1)

6.2.3 Summary of Illustrative Scales Study

Although an illustrative study only, responses suggest that high school age students, like their older counterparts, teacher trainees, hypothetically first look for scale boundaries that are large scale, and then refine the boundaries that match their experiences. In terms of time boundaries, students rarely have boundaries that encompass geological time. Time scales appear to begin at the 'seconds' level or at the birth age of the individual. Although 'millions of years' is stated in some responses, geological time as a boundary is in this study not differentiated. It is simply not within the experiences of most students despite minimal exposure in the New Zealand National Science Curriculum (See chapter 9). Respondents appear to have their own unique view of mental size scale boundaries. This small study supports the findings of Trend (2001b; 2001c) and that of Tretter et al. (2006) with regard to the 'lumping' of time and other scalar values. There is much room for further research on this critical learning aspect for science literacy.

6.3 Replicating 'Boundaries of Size' Scales

Tretter et al.'s findings (2006) are based on the previous work of Trend (2000) in an investigation of understanding of geological time, and attempts to identify conceptual scale boundaries of size by using a "Scale of Objects" (SOQ) questionnaire and a rank card sorting exercise of size of objects. This study does not replicate any card sorting exercise as outlined in Tretter et al. (2006). Comprehending conceptual boundaries of scale is fundamental to a conception and perception of geological time. Trend's work (and this thesis) focuses on geological time but conceptions and perceptions of scale are intimately related to each other. An attempt to replicate Tretter et al.'s questionnaire was conducted with a New Zealand Year 9 class (aged 13 years, and the same group used in the illustrative study above where n = 18), and a Year 12 class (aged 16 years and also the same group used in the illustrative study where n = 22). With minor modifications made to 'fit' a New Zealand context, the 'size objects' were identical. Appendix 4 presents the 'Scale of Objects' questionnaire adapted and modified from Tretter et al. 2006 that was given to students.

6.3.1 Responses of Year Twelve Students to 'Boundaries of Size' Scale

Tables 6.7 and 6.8 in Appendix 4 show the response distributions of scales of size of common objects for a class of 22 New Zealand Year 12 students (average age of 16 years 6 months) and a class of 18 Year 9 students with an average age of 13 years and 4 months. The NZ Year 12 (age 16 years) student results indicate a closer agreement with actual results and considerably less 'fuzziness' at the extreme ends of the scale. In other words, older secondary school students seem to have less indecision at the large and small scale ends of the size of objects. Actual results indicate a linear hierarchy, and these year 12 students responses approach this pattern more closely than Year 9 (age 13 years) students. Objects 1 (width of human hair) 9 (diameter of a human cell), 14 (diameter of a bacterium), and 4 (diameter of a virus) posed the most difficult sizes to distinguish. Question one was evenly split between the actual and one magnitude different. The evidence suggests that this cohort 'lumped' these inexperienced small sizes together as 'unknown'. Similarly, the 'large sizes' (questions 18, 3, 5 and 13 in Tables 6.7 and 6.8 in Appendix 4) seem to have provided similar problems of differentiation. Familiar items such as human height, elephant height and school bus size seem to be the 'reference' point for size comparison - familiar to inexperienced. The Year 12 students have difficulty in deciding the width of a human hair. The indecision on the length of a football field is explained by half deciding it is less than 100m and the other half deciding on more than 100m in length. Students were not given direction on whether the 100m 'boundary' was inclusive or exclusive; they just had to make a decision.

6.4 Looking at Scales of Mass

When a different class of 30 students aged 13 (Year 9) were asked individually to 'guess' the mass of a tablespoon of salt they grossly underestimated this mass. For example, the mean mass given by this class was 15.2 g with a range of 9.5g (one student) to 21g. The actual was 9.5g. When one student was asked to explain how they arrived at his answer, he stated that "they had heard that one tablespoon was 10mL" and thought that it was "just little bit more than this". This student had confused volume of 10mL for mass. So, for this student, the mass was given as the only value he knew about a tablespoon. For 13 year olds, the concepts of mass and volume appear to be very blurred and when asked if they really had no idea, a third of the class put their hands up. The same question under the same conditions was asked of 14 year olds through to 16 year olds. The results of this age group comparison is shown in Table 6.9.

Table 6.9. Mean response distributions for scale of mass of a tablespoon of salt.

NZ Year Level	Class Mean (Actual = 9.5g)
9	15.2g
10	16.4
11	13.6
12	12.1

6.4.1 Discussion of Responses of Year Nine Students

Year nine students' responses (Table 6.11 in Appendix 4) indicate considerably greater difficulty differentiating size of objects large and small, outside their common experiences. This is shown by the accurate identification of sizes of objects close to familiar things and easily scale referenced from the size of an elephant or the human body. The relative visualisation of lengths less than 1/100th of a millimetre and lengths greater than 'a long car journey' seems to defeat many younger students but fewer older students. Age and experience refine conceptual scale boundaries of size of objects.

6.5 A Multivariate Cluster Analysis of Size Responses

Tables 6.10 and 6.11 and Figures 6.1 and 6.2 illustrate an attempt to identify respondent age differences in the statistical size clustering of an objects' size. Analysis was carried out using minimum variance clustering for MVSP vers.3.13n (Kovach, 1998). Groups or clusters are generated from numbers of responses (decisions) for each size category presented in the questionnaire. Cluster lists are not ranks but merely represent clusters of responses of equal variation. Being a tiny sample, it is dangerous to make general conclusions.

Comparing Year 12 and Year 9 data shown in Tables 6.10 and 6.11, younger (Year 9) students have greater difficulty separating and refining small size and large size objects than do older year 12 students. This finding is shown by the Year 9 group having more clusters and being much less defined. Cluster 4 for the Year 9 cohort indicates confidence in judging size of objects within their experiences with much less confidence in the other clusters. This is similar to the Year 12 cohort cluster 2 with a less clear confidence with the very large and the very small. Some decisions such as a football field being in the same cluster as the size of a virus is more difficult to explain. Perhaps the cluster result indicates difficulty in deciding whether a football field is less than or more than 100m. Do they know?

Table 6.10. Year 9 cluster groups for scale of size rankings.

Cluster 1	Cluster 2	Cluster 3
Earth to Moon	Rice grain	C atom nucleus diameter
Earth to Sun	Ant length	Virus diameter
Auckland to Invercargill	Postage stamp	H atom diameter
Satellite altitude	Pencil length	Human cell diameter
Earth diameter	Human height	Bacteria diameter
	Elephant height	Human hair diameter
	School bus	
	Football field	
	Pine tree	
	Tallest building	

Table 6.11. Year 12 cluster groups for scale of size rankings.

Cluster 1	Cluster 2	Cluster 3	Cluster 4
Human hair diameter	Satellite altitude	Auckland to Invercargill	Rice grain
Earth to Moon	H atom diameter	Human cell diameter	Pine tree
Football field	Elephant height	Tallest building	Earth to Sun
Virus diameter		H atom diameter	School bus
Earth diameter			Postage stamp
			Pencil length
			Bacteria diameter
			Adult height

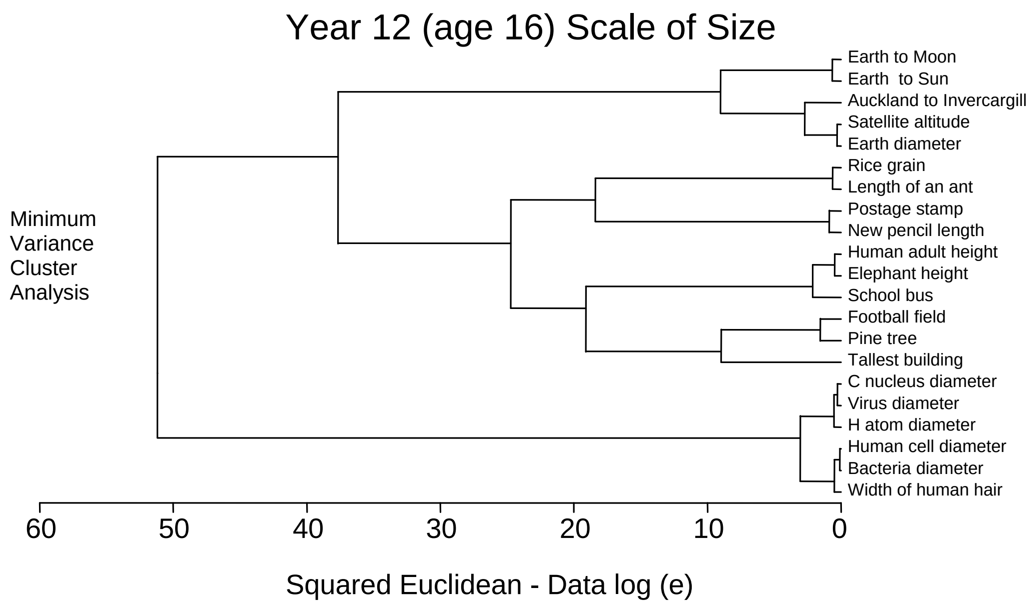


Figure.6.1. Cluster analysis (dendrogam) for Year 12 responses for scale of size.

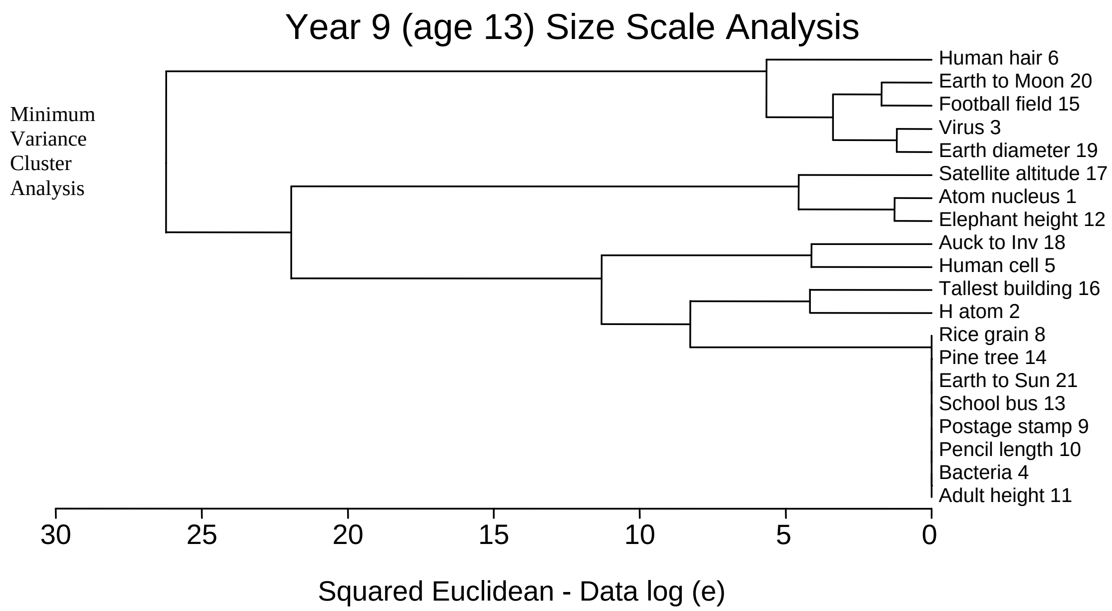


Figure. 6.2. Cluster analysis (dendrogram) of Year 9 responses for ‘size’ scales.

For comparison, a modern scale of time (Table 6.12) with their units has been produced by Labrador (2006) where physical measurement of durational time stretches from attoseconds to billions of years. It is likely that students perceive all those units below one second as being lumped together with other boundaries of time at one second, one year and then in centuries and then in millions. A million years appears to be perceived as being no different to millions of millions of years. As Einstein said, “The only incomprehensible thing about the universe is that it is comprehensible” (Life Magazine, 1950, p.10).

Table. 6.12. Scale and units of time (modified from Labrador, 2006) Note that this has been arranged ‘geologically’ from the oldest at the bottom to the youngest at the top)

Time Unit	**Description**
Planck Time	10^{-43} second: the shortest possible time duration.
Attosecond	Billionth of a billionth of a second
Femtosecond	Millionth of a billionth of a second
Picosecond	Thousandth of a billionth of a second
Nanosecond	Billionth of a second
Microsecond	Millionth of a second
Millisecond	Thousandth of a second
Tenth of a second	
Second	
Minute	
Hour	
Day	Comprehensible human experiences of time
Year	
Century	
Thousand years	
A Million years ago	Near the end of the Cenozoic era and appearance and dominance of *Homo.erectus.*
A Billion years ago	Near the beginning of the Paleozoic era
Billions of years ago	Age of the Earth at 4.6 billion years ago Age of the Universe at 13 to 15 billion years ago

6.6 Other Geological Scales

The scalar concepts of earthquake magnitude and intensity provide a unique dilemma for many students. How and where do they place these concepts onto their categorised mental scales? Earthquake magnitude is concerned with energy release and ground shaking motion. Intensity is concerned with what is felt and seen during energy release. There is only one magnitude for each earthquake but many intensities depending on how far away from the epicentre an individual is. There is often confusion between ‘feeling’ kinaesthetic scales and instrumentally measured and calibrated ‘number’ scales and student discussions of earthquake magnitude often reveals (anecdotally) an inability to grasp the idea of the ‘Richter scale of magnitude’ as being open ended and that like a temperature scale, it is theoretically possible to have a negative earthquake magnitude. For students whose experiences and scales of number only begin at zero, this is hardly surprising. The student responses for both age groups suggests that very few have a grasp of numbers stretching less than zero. It is as if numbers start at zero (or one) and go forward to infinity for many students although one older student did conceive of an infinite negative and an infinite positive. The ‘Now’ ‘Me’ ‘Zero’; equivalents are the beginning scalar boundary reference points. For older students who do have a grasp of negative numbers, these students fail to grasp the connection between energy release and ground shaking motion as measured on a scale based on calibrated instruments. Refinement and conceptual differentiation of scale proceeds with age. Nieto-Obregon (2001) has devised a useful circular ‘chronoscalimeter’ for aiding visual perception of relative geological time.

Development of an understanding of scale then is experiential in nature and it seems that people also have a genetically innate sense of number, size, time and relativity which is triggered by experiences of the natural world’s four dimensions. Survival in the ‘real’ biological world depends on the ability to make the right judgements based on experiences of the physical world. In the words of Gee (1999) *“Deep Time is like an endless dark corridor, with no landmarks to give it scale”* (p. 26). It is the teachers’ challenge to interpret the landmarks that <u>are</u> visible (such as the fossil record, radioactivity and starlight) and the means of finding new ones (field relationships) to help make sense of geological time through provision of tactile and theoretical student experiences of geological time.

6.8 Looking at Time and Biological Evolution

Understanding biotic evolution is impeded by the difficulty in comprehending the nature, tempo and meaning of geological time. As D’Arcy Thompson (1942) stated in his attempt to comprehend the different worlds of people, insects and bacteria, "The predominant factors are no longer those of our scale; we have come to the edge of a world of which we have no experience, and where all our preconceptions must be recast" (p. 771). Little wonder that discussion of geological time and biotic evolution shakes confidence and rattles conceptual worlds. There is little dispute that the greatest contribution the Earth sciences have provided to our conceptualisation of the world is that of geological time (Gould, 1987; McPhee, 1981; Orion & Ault, 2007). However, it is the nestling of biological evolution within a 'proper' scale of geological time that causes the greatest disturbance. As mentioned in Chapter 4, the intertwined conceptual worlds of gradualism and punctuationism offer scientific theory explanations for the observable fossil record and possible mechanisms of evolution, but the power of worldview religious social constructs (such as biblical Judeo-Christian thought and the Qur-an of Islam) confuse the paradigms of science and religion as explanations of the natural world, in this case, geological time and biotic evolution. In Islamic thought, scientific evidence is in the service of God where the understanding of nature is a kind of bridge to getting closer to God (Dagher & Boujaoude, 1997). These religious ideas directly influence the way people construct their view of biotic evolution and geological time.

Gould (1987), attempts to metaphorically rationalise the historical march of time as a directional 'arrow' with intertwined cyclical repetitions of mechanisms. For example, biotic homologous structures is a term used by biologists for describing shared features generated along the historical arrow of time and analogous features is a term used for describing similar functional structures within repetitive but separate cycles of time within different taxonomic lineages. The use of homology and analogy is recognition of arrows and cycles of events through time. Little wonder that young students (and old) struggle to make sense of naturalistic biotic evolution on a time scale that is beyond their experiences. Global Earth Science curricula (Chapter 4) reflect these conceptual and historical difficulties of matching geological time with biotic evolution. Fossils, as the remains of once living organisms preserve the homologous record of times arrow through countless analogous intertwined spirals. These spirals are blindly directionless (See Figure 6.3) and simply represent an organism's response to environmental change (at that point in time) and are not responses to "times arrow". Times arrow is independent and exists as a by product of natural events. As are oxidation and reduction and electricity and magnetism to chemistry and physics, so to are cycles and arrows of time to geology. Without the connection to deep geological time, patterns and mechanisms of biotic evolution become meaningless. Evolution is indeed a ‘blind’ populational DNA response to environmental change and is independent of time (Dawkins & Wong, 2004; Mayr, 2001).

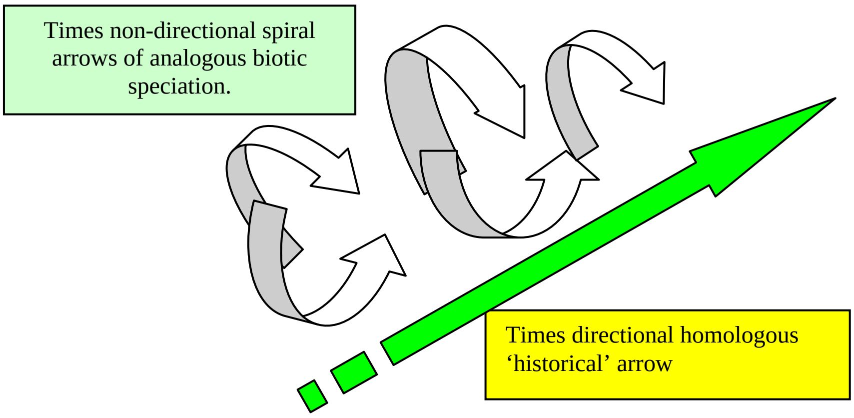
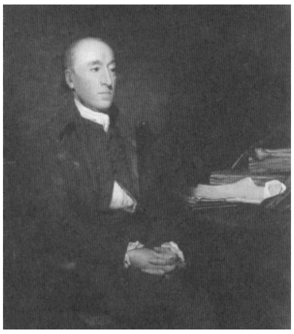


Figure 6.3. Times ‘progressive arrow’ versus ‘analogous speciation’

The early eighteenth century western intellectual world was (and is?) dominated by Judeo-Christian religious views of a progressive evolution of the Earth. Consequently, it is hardly surprising that a realistic scale of geological time was not clearly understood when James Hutton (Hutton, 1788) wrote his now famous closing lines: “The result, therefore, of our present enquiry is, that we find no vestige of a beginning,--no prospect of an end”, (p. 304). But of course there was a beginning, one simply beyond comprehension at the time. It is interesting to note that the first part of this famous quote (“The result, therefore, of our present enquiry is…..”), is rarely included and suggests that Hutton was aware of other peoples’ research (and controversies of the time such as neptunism versus plutonism), and the potential research that might provide refinement to his concept of never ending cycles of change through his perceived scales of unimaginable geological time. Refinement of deep geological time and the evolution of life within this framework eventually came (amongst many others), with Lyell, Darwin, Wallace and Holmes. Hutton was also keenly aware of the continual nature of time (“Times Arrow”)? and his thinking began the conceptual changes needed for a better comprehension of Earth’s history.

James Hutton (1726-1797)

"….the course of nature, cannot be limited by time, which must proceed in a continual succession"
(Hutton, 1788, Vol.1, part 2, p. 215)



(http://www.amnh.org/... /earth/p_hutton.html)

6.9 Concluding Comments

This chapter has looked at the geological time aspects of research question 3: *What is the influence of diachronic thinking on conceptions of geological time, structures and fossils?* Discussion has been further developed into investigations of student conceptualisations of scale and found that teaching and learning about scale is likely to be a significant factor in the development of scientific conceptualisations of geological time and its application to geological phenomena.

Landscapes, like life, evolve through time, and in conclusion to this chapter a pictorial metaphor for geological time by Salvador Dali's 1934 warped sense of a decomposing, dripping and melting clock (which is neatly and subtly connected to a geological 'natural' landscape theme, and complete with vertical strata in the bottom right hand corner), seems to sum up how people conceive and perceive but fail to comprehend the infinite vastness of deep geological (and space) time. The uniqueness of geological science lies in its contribution to learning and scientific literacy by application of scales of time to earth history. The challenge for educators is to find effective ways of developing in students a geological sense of time and one that connects with biological, physical and chemical evolution.

(http://www.allposters.com/-sp/Clock-Explosion_i96971_.htm?aid=999826)

CHAPTER SEVEN

SPATIALISATION AND GEOLOGICAL STRUCTURES

Geology fieldtrip, West Coast New Zealand

7.1 Introduction

Research question 2 asks:
How do students aged between 12 and 40 develop their conceptions of evolution and the fossil record, geological time and 3-D geological structures?

Research question 3 asks: what is the influence of visual/spatialisation on conceptions of geological structures? The ability to spatially reason and visualise hidden structures and infer their deformational histories is an important aspect of geological science not only at a macro scale but also at a micro scale. Spatialisation ability is investigated with the use of the GeoTSAT instrument given to the following cohorts. Note that respondent sample sizes are shown in Table 5.3, Chapter 5.

- American University of Beirut (AUB) Primary Teacher Trainees
- AUB Secondary Teacher Trainees
- University of Canterbury (UC) Secondary. Teacher Trainees
- UC 1st Year Geology students
- UC 2nd Year Geology students
- UC Geology Post Graduates
- Ashburton College (AC) Year 13
- AC Year 11
- Israeli (IS) Grade 8
- IS Grade 10
- IS Grade 12

This chapter is an attempt to piece together primary data from students aged 13 years to graduate (40 years) on the GeoTSAT instrument, for their conceptualisation and visual-spatialisation reasoning for 3-D (block diagram) geological structures (see Appendix 2). This wide range of respondent age and culture provides a control for mono cultural bias and enables age related geospatial comparisons.

It is the visual penetration ability component that is specifically addressed in this thesis and further investigated, discussed and described in Chapter 8). Although surface developments and rotations are important aspects of geological structures, solving geological structure problems uniquely involves VPA. Visualising hidden three dimensional directions of rock strata and being able to place oneself inside a cube and look outwards in 3-D for example are skills that are valuable for understanding geological structures. Further investigation of VPA was specifically suggested as a 'fruitful' area of future research by Kali and Orion (1996).

To make sense of geological structures, their origin, history and reconstruction, necessitates the ability to visualise hidden structures based on fragmented and disoriented surface features. The teaching and learning of geology uniquely enables development of this visual penetrative spatial intelligence and enhances and combines this ability with the real world of fieldwork. The research challenge is to investigate the factors that trigger spatial abilities that are connected with geological structures and to implement these findings into the classroom.

As Libarkin and Brick (2002) state; *"….the development and validation of tools for the assessment of visualisation in the Earth Sciences is a relatively untouched field of research"(p.453),* and indeed, with the power of current computer modelling and game theory, students are persistently exposed to visual and kinaesthetic learning as opposed to audio learning. The challenge is to develop cognitively manageable, economically cheap and conceptually sound visualisation software for enhancing the development of 3-D to 4-D spatial visualisation of geological phenomena. Table 7.1 shows subject areas within the New Zealand curriculum in which students require spatial – visualisation skills. Most New Zealand students then are exposed to a variety of curriculum areas that provide them with an opportunity to develop their spatialisation abilities albeit with restricted time within each discipline area. Continuity of development is best placed within mathematics and the sciences.

Table 7.1. New Zealand curriculum with visual-spatial components.

Subject Area	**Topic with a visual-spatial component**
Mathematics	Tessellations, reflections, rotations, geometry
Graphics	Technical drawing, computer aided design, building plans
Art	Cubism, tessellations, portraits, theatre scenic art.
Geography	Location, maps and mapping, geographic information systems
Chemistry	Molecular and atomic shape rotations
Biology	Ecology, cell structure and shape, organic molecules.
Physics	Harmonic motion, Newtonian mechanics.
Astronomy	Structure of the Universe, stars, galaxies, space.
Geology	Structures, interior, volcanism, seismology, sequencing, correlation.

As mentioned in Chapter 2, recent work (Blazhenkova, & Kozhevnikov, 2009; Kastens, 2010; Kozhevnikov, Kossly, & Shepard. 2005) have firmly placed geospatialisation skills within a definable cognitive learning style where individuals tend to be ‘spatially’ or ‘object identification’ oriented. This appears to have a likely genetic component for use of different neurological pathways in the brain (Blajenkova, Kozhevnikov & Motes, 2006a). Geospatial abilities such as VPA require both attributes. The challenge for geoscience educators is to develop programmes of instruction that cater for both learning styles that will develop geo-visual spatialisation abilities. For example, identification and classification exercises and activities for rocks, minerals and fossils and tasks for mental rotations and VPA for geological structures and ICT enabled, await exciting future development.

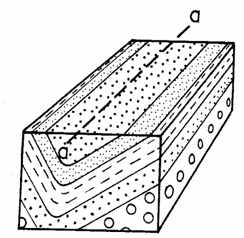
7.2 Rationale for the Geo-Spatial Structures Questions

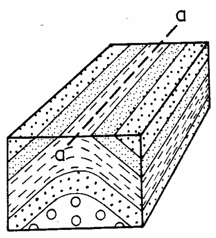
Block diagrams (See Appendix 2 for the GeoTSAT instrument) were used to test visual/spatial ability to draw strata continuation in folded strata (Questions 7a-d) and tilted (Question 8b) strata geological situations. This corresponds to Kali and Orion’s (1996) validated tests of ‘completion’ questions 8a and 8c, cross sectional ability as well as visual penetration ability. The ability to translate in what Kali & Orion called a 'construction' test where a simple geological surface map is required to be translated into a cross section was not tested in this GeoTSAT but was tested in the GeoVAT instrument in Section B, question 2a (See Appendix 5). The results to this are fully discussed in Chapter 10. No instructions were given on what a cross or transverse section is, nor were respondents told that strata were of equal thickness, and that there may be more than one correct answer. Responses were entirely undirected and 'raw'. Table 7.2 shows the types of structure and spatialisation required for each question.

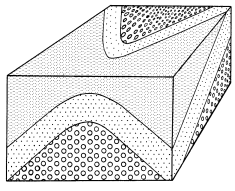
Table 7.2. Required GeoTSAT geological spatialisation skills.

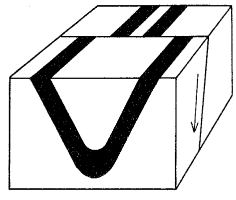
Geological structure	**Spatialisation Skill**
Non geological: letters e and G (Q6)	Mental rotation
A horizontal syncline (Q7a)	3-D surface continuation of strata
A horizontal anticline (Q7b).	3-D surface continuation of strata
A plunging anticline (Q7c).	3-D surface continuation of strata and VPA
A faulted horizontal syncline (Q7d).	3-D surface continuation of strata and VPA
Plunging syncline (Q8a) and a sphere (Q8c).	Cross Sectional rotation and VPA
Inclined flat layers (Q8b).	Cross sectional rotation and VPA

The following diagrams illustrate accepted models used in the GeoTSAT instrument and based on that of Thomas (1966).







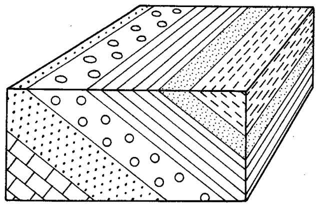


Questions 7c and 8a

(Plunging anticline)

Question 7d

(Faulted horizontal syncline)



Question 8b

Inclined horizontal strata

A sphere

Student responses were compared to the accepted ‘answers’. The horizontal syncline (7a) and horizontal anticline (7b) indicate a simple fold of strata and assuming no overturning of strata. Diagrams show the three surface patterns when sliced through three different axes. Question 8b is more complex in that an anticline (upfold of strata) has also been tilted towards the observer and subsequently planed off. This produces different surface patterns on the three faces of the block. Question 7d introduces the combination of a horizontal syncline cut by a fault. Students were required to spatially visualise the surface pattern for this combination. Question 8b was a simple originally horizontal sequence of strata that had been tilted with no folding. Question 8c asks students to visually penetrate the inside of the Earth when cut through the middle. In effect this means respondents are required to be able to visualise a transverse section of a sphere.

Respondents were asked to draw the continuation of strata on each exposed face of the block diagrams or to draw a cross section. Questions 7 a, b, c and d had two faces exposed. Question 8a required two cross sections at right angles to each other. To be completely correct respondents needed to be correct for question 7c. Question 7c was essentially looking for a response that showed up-folding of strata on the front face of the block diagram. Insufficient data prevented any evidence of gender differences in responses. Appendix 7 presents the results of student responses to their spatial reasoning of these typical geological scenarios. ANOVA of cohorts for questions 7 and 8 of the GeoTSAT instrument (See Appendix 8) suggest that that are differences in the means for correct responses but that these differences are largely due to age and experience rather than the kinds of spatialisation difficulties exhibited. Despite increased probability of type-1 errors this is elucidated by t- test analysis.

7.3 Summary and Discussion

This chapter discusses general issues of geospatialisation skills such as VPA and describes the rationale for the geological structure exercises in the GeoVAT and GeoTSAT questionnaire instruments. It builds on the work of Kali and Orion (1996) and provides supporting evidence for how respondents across all age groups prefer to copy existing block diagram faces when unsure or are unable to visually penetrate hidden structures. Although the importance and significance of spatial reasoning within geological science has long been understood, (Bradshaw, 1969; Chadwick, 1978), only recently have these abilities begun to be investigated (Ben-Chaim, 1988; Ishikawa, & Montello, 2006; Kastens, 2007; 2009; 2010; Liben, 2009). VPA is a critical attribute for making sense of geological structures not only from field mapping but also from modern use of 3-D software. This chapter briefly investigates and builds on the earlier work of Kali and Orion with respect to a validated instrument being but one used and adapted for a wider age range of respondent. Chapter 8 expands on the use of 'hands on' modelling for investigating VPA. The evolution of crustal deformation through time is unique to geological science and the visual spatialisation and comprehension of this is crucial for making sense of earth history - the aim of geological science and probably all sciences. As the technologies of gps and GIS are extended, so will our 3-D understanding of geological structural deformation.

Although each geological block diagram in the GeoTSAT instrument has its own set of difficulties, recording the **total mean** percentages for **incorrect** responses across all cohorts provides a measure of VPA difficulty as presented in the structural problems. The findings are summarised in Figure 7.1.

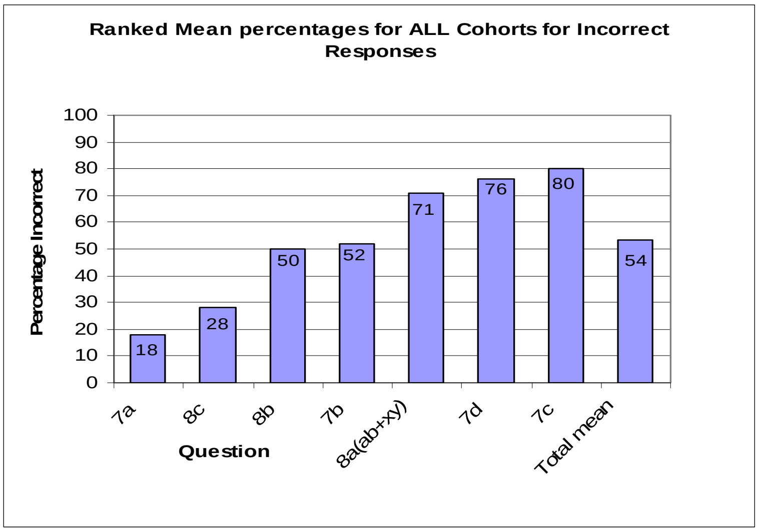


Figure 7.1. Ranked degree of VPA difficulty for geological structures.

Not surprisingly, as structural complexity and VPA demand increases, the percentage of correct answers decreases. Although only one face is required to be completed, Q7c caused the greatest difficulty across all cohorts. This is likely to be a result of the high VPA demand caused by the **hidden** direction of a pitching anticline and the need to visualise how different planar sections effect the strata directions. It also presupposes prior knowledge about geological structures. It is unlikely that any of the cohorts other than post secondary geology students would have this knowledge. In New Zealand for example, geological structures (in any form) are not taught at secondary school and so responses are purely those of ’native’ or naïve VPA. The mean percentage of *correct* responses for all cohorts for all questions is 54% suggesting that there is a degree of VPA already developed but also that VPA remains highly underdeveloped even into graduate level and especially for teacher trainees (See Figure 7.10). Not surprisingly, geology students at second year level and graduate level have the most developed VPA suggesting the power of specific training and learning experiences such as fieldwork (See Figure 7.10). There is little doubt that developing valid and well resourced learning experiences with a strong connection to the real world outside the classroom and ‘up close’ to a rock exposure enhances visual spatialisation. However, it is only in fieldwork that dimensionality, scale, complexity and new investigational problem solving skills can be taught (King, 2008). With augmentation from information technology, connecting the real world to the virtual world further enhances spatialisation skills (Orion et al. 1997; Riggs, 2004; Riggs, & Tretinjak, 2003; Smith, 2005).

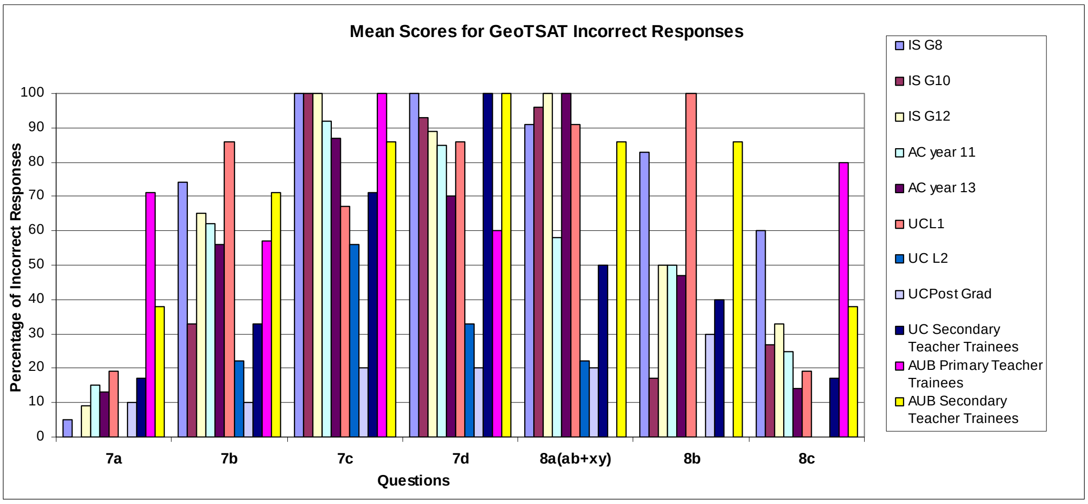


Figure 7.2. Percentage of incorrect responses by age group.

Question 7d is similar to 7c in difficulty largely because of the VPA required to 'see' the effect of vertical disruption on the syncline. Most answers were correct for the side face but not the top face as well.

Figure 7.11 shows the incorrect responses per question per age group and combines the **mean incorrect** responses for the GeoTSAT spatial structure questions. The overwhelming finding is that geology students are significantly advanced in VPA relative to other cohorts, but there is little difference between all other age groups. Indeed, graduate teacher trainees are little different in their VPA than the children they will be teaching. For example only 16% of University of Canterbury postgraduate geology students were incorrect for all structural VPA questions, but there was effectively no difference between the AUB secondary, AUB primary and Israeli 13 year olds in percentage of correct answers. Although the NZ secondary teacher trainees do not score well in questions 7 and 8 of the GeoTSAT instrument (Mean of 53% correct responses), they have performed significantly better than their AUB counterparts who are from a different social culture, school and university curricula. Possible reasons for this include the degree and content of geological science exposure in school curricula and exposure to fieldwork where geospatial experiences are part of object identification and spatial learning. Identifying what geological objects are from unusual spatial orientations is a first step to unravelling structural histories. Comparing responses from isolated and 'independent' samples provides information that generates further research questions.

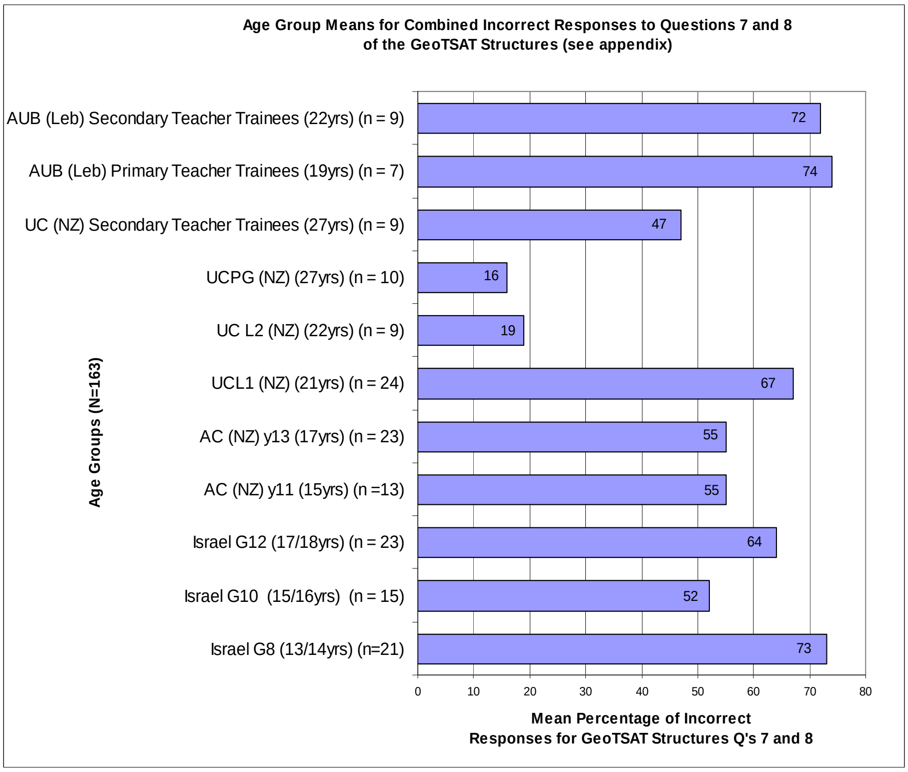


Figure 7.3. Mean percentages of incorrect responses per age group.

The findings in this small study (See Chapter 8 for the details of student responses to the VPA investigation), confirm that spatial reasoning is a critical area for a meaningful unravelling of earth's structural history and that learning geological science is another tool that enables an individuals visual-spatial development: a key competency that is often absent from or minimalist in school curricula (Liben, Kastens, Agrawal, Christenson & Myers, 2009). Underdeveloped spatial reasoning reflects curriculum priorities and histories. Although significant progress has been made with 3-D virtual reality (VR) tools using Geographic Information Systems (GIS) (Bo Huang & Hui Lin, 1999; Dong, Hu & Wang, 2010; Smith, 2005), specific application of VR to geological processes and in particular, geological structures education, remains a work in progress (Kali, Orion, & Mazor, 1997; Kali, 2002; 2003). In the end, it is likely that for a full appreciation of geospatial relationships connection with the real world as in the field will be required. Improved understanding of the neurocognitive mechanisms and connections with VR presents a rich area of future research. VPA is particularly important to the geological sciences as the Earth is mostly hidden from view and being able to 'see inside', rotate and mentally manipulate observable geological surface patterns provides a unique way of making sense of geological history. Orion and Ault (2007) sum up the significance of developing geospatial skills that are diachronically related:

> *Making sense of earth's processes and patterns, structures and changes, systems and cycles, depends upon visualization and spatial reasoning as well as recognising bias in the human-scale perception of events.*
>
> (Orion, & Ault (Jr), 2007, p.66.)

CHAPTER EIGHT

3-D MODELLING AND VISUAL PENETRATION ABILITY (VPA)

8.1 Introduction

This chapter addresses specifically the 3-D visual/spatialisation aspects of research questions 2 and 4:

Research Question 2
How do students aged between 12 and 40 years develop their conceptions of evolution and the fossil record, geological time and 3-D geological structures?

Research Question 4
What is the influence of visual/spatialisation on conceptions of geological structures?

As discussed in Chapter 7 the perception and interpretation of rock deformation relies on the ability to visually penetrate in the' minds eye' as it were, solid rock. During tectonic activity rocks in the right physical position and condition are able to deform plastically and produce complex styles of folding and refolding. Faulting or breaks in rock strata occurs in more brittle rock. Discussion in this chapter is restricted to investigating VPA for a simple geological fold structure but across a wide age range of respondents.

8.2 Method

Developing and using a 'hands on' 3-D model for investigating VPA was selected as an additional triangulation of questionnaire 'paper and pen' exercises for geological structure problems. It has always struck me that so many teenage learners (especially boys) are highly kinaesthetic and that being able to touch and manipulate a 3-D model of a simple geological structure may provide a confidence that looking at a 2-D representation couldn't. Exposing learners to 'real' 3-D problems rather than 'virtual' 3-D pictures was a positive and indeed added interest and curiosity to geological structures problem solving. The key value in the use of 3-D models is their ability to be ‘pulled apart’. Learners want to see their answers and, as McLeay (2006) pointed out, it also caters for different learning styles. The results to this study triangulate with the GeoTSAT paper and pen exercises for VPA.

A small plasticine model (Figure 8.1) was presented to individual students (with no collaboration with other students) for investigating their VPA. Plasticine was selected because of its ability to be used many times and ‘fixed’ many times. It consisted of a simple two layer anticlinal fold structure (Figure 8.1). Students from available classes at a New Zealand secondary school of ages ranging from 13 to 18 and their science graduate teachers were individually asked to draw what they thought the inside surfaces would look like (VPA) after the structure was cut with a knife and pulled apart. Unlike Titus and Horsham’s study (2009) where the VPA exercise consisted of a single angled transverse cut, this study included section cuts which were longitudinal, vertical transverse (or cross) and diagonal.

Research question 4 asks how visual spatialisation influences the development of conceptualisation of geological structure. Understanding geological structure and the history of deformation requires a spatial ability, which for geology is largely VPA. In response to research question 2 this chapter investigates the status of VPA in a small sample of students but across a wide age range (13 years to adult age). Developing ways of teaching VPA and other spatial skills is dependent on having an understanding of perceptual and conceptual spatial status.

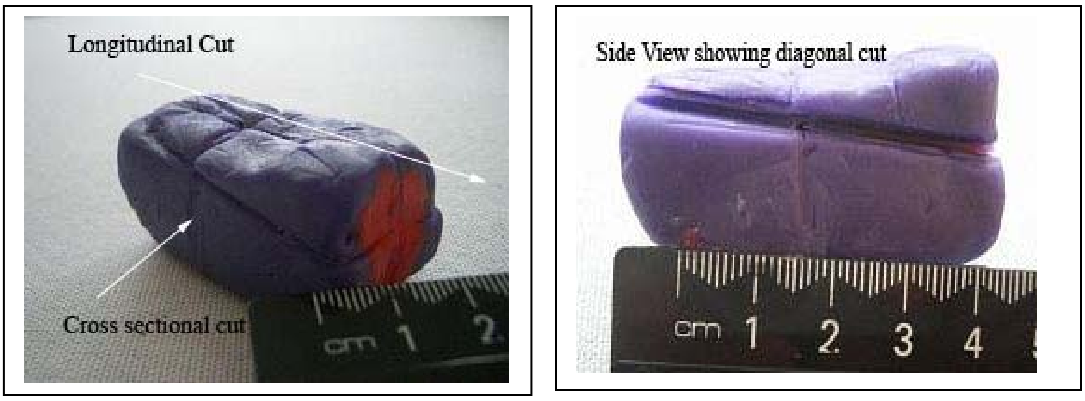


Figure 8.1. Plasticine model used for VPA investigation.

For the diagonal cut, students were asked to draw what they thought the upper surface in plan view (looking down on the top surface) would look like when the cut diagonal 'lid' section was removed. Completion requires mental rotation and VPA.

8.3 Results

Correct responses to models sectional cuts are shown in Figure 8.2 and all results are detailed in Figures 8.2 to 8.8.

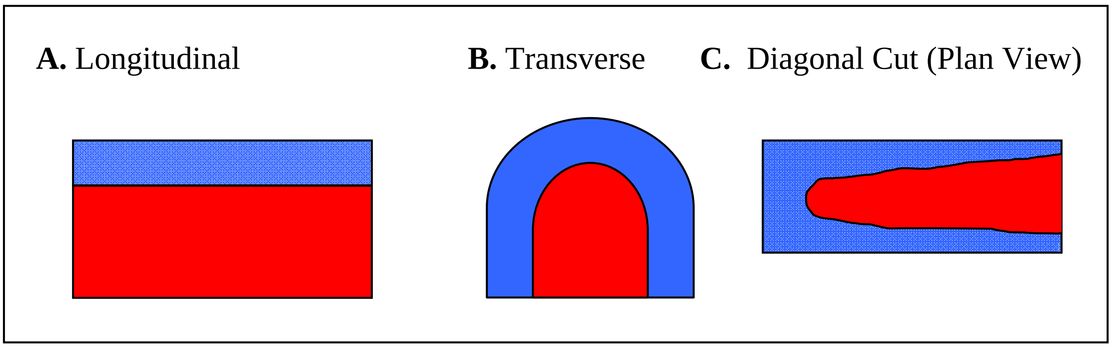


Figure 8.2. Correct responses for 3-D model sections.

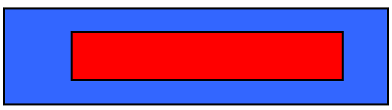
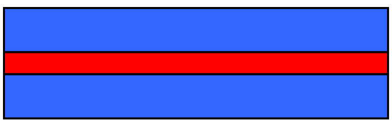
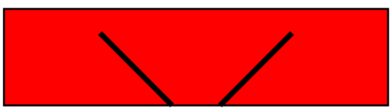
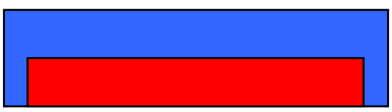
	Category Responses for Longitudinal Section (n = 13)		**NZ Year 9 age 13/14 years** Female	Male	Total
1.	Correct two horizontal strata		2	1	3
2.	Rectangular centre with variations.		2	1	3
3.	Central horizontal strip		2	3	5
4.	Other		0	1	1
			0	1	1

Figure 8.3. NZ age 13/14 years responses to longitudinal section.

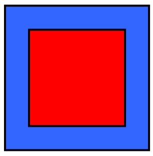
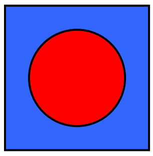
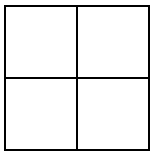
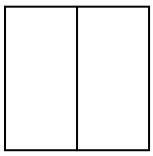
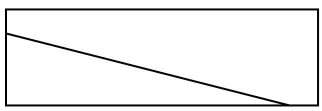
	Category Responses for Cross Section (n =16)		**NZ Year 9 Age 13/14** Female	Male	Total
1.	Correct		2	3	5
2.	Other		2	4	6
			1	1	2
	No colour recorded		1	1	2
	No colour recorded		0	1	1

Figure 8.4. NZ age 13/14 responses to cross (transverse) section.

	Category Responses (Plan View)	**Diagonal Section**	**NZ Year 9 Age 13/14 years** Female	Male	Total
1.	Correct		2	3	5
2.	Diagonal split		2	0	2
3.	Central horizontal strip		2	2	4

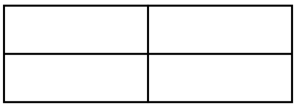
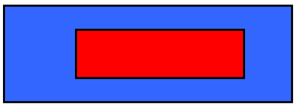
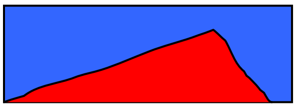
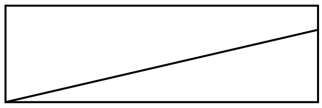
	Category Responses	**Diagonal Section**	**NZ Year 9Age 13/14 years**		
	(Plan View n = 7)		Female	Male	Total
3.	Other		1	0	1
			1	2	3
			0	1	1
			0	1	1

Figure 8.5. NZ age 13/14 years for diagonal section.

	Category Responses	**NZ Year 11 Age 15/16 years**		
	Longitudinal Section (n =13)	Female	Male	Total
1.	Correct	4	3	7
2.	Central horizontal strip	6	5	11
3.	Central rectangle	2	3	5
4.	Cross section pattern copy	0	1	1

	Category Responses	**NZ Year 11 Age 15/16 years**		
	Cross Section	Female	Male	Total
1.	Correct	5	3	8
2.	Circular Centre	2	5	7
3.	Rectangular Centre	4	3	7
4.	Blue top and bottom strips	1	0	1

	Category Responses	**NZ Year 11 Age 15/16 years**		
	Diagonal Section (n = 15)	Female	Male	Total
1.	Correct	2	4	6
2.	Central horizontal strip	7	2	9
3.	Rectangular Centre	3	5	8
4.	Other 	0	1	1

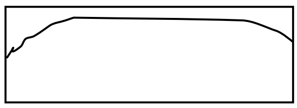
	Category Responses	**NZ Year 12 Age 16/17 years**		
	Longitudinal Section (n = 12)	Female	Male	Total
1.	Correct	3	1	4
2.	Central horizontal strip	1	1	2
3.	Rectangular Centre	2	1	3
4.	Other 	1	1	2
		0	1	1
				

Figure 8.6. NZ age 16/17 years for longitudinal section.

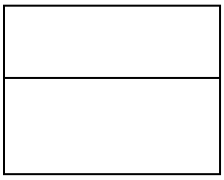
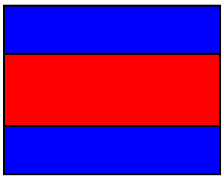
	Category Responses		**NZ Year 12 Age 16/17 years**		
	Cross Section (n = 9)		Female	Male	Total
1.	Correct		4	2	6
2.	Circular Centre		2	0	2
3.	Other		0	1	1
			1	0	1

Figure 8.7. NZ age 16/17 years responses for cross section.

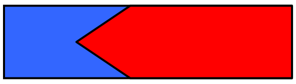
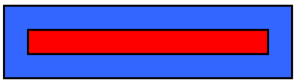
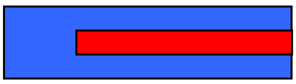
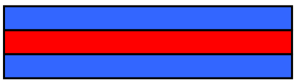
	Category Responses		**NZ Year 13 Age 16/17 years**		
	Diagonal Section (Plan View) (n = 11)		Female	Male	Total
1.	Correct		1	0	1
2.	Other		1	0	1
			1	1	2
			4	1	5
			0	2	2

Figure 8.8. NZ age 16/17 years responses for diagonal section.

8.4 Discussion

> *"…reasoning for non-penetrative answers showed a dependency of students on the patterns exposed on the external faces".*
>
> (Kali & Orion, 1996, p.383.)

In other words, students who are unable to visually penetrate a solid object in terms of visualising where rock layers might extend to rely on guessing this internal extension from the pattern they see on the outside. After all, what other choices do they have if they can not 'see' inside the structure? For example, Year 9 students typically draw the lines which correspond to the 'cut marks' on the outside of the model but do not know where to actually put them. They know that they do not know. Nearly all students were very keen to be shown 'what the answer is' and often exhibited surprise when shown the answer by the 'opening up' of the model either as thinking that they were right but did not express their thought or surprise that they the answer was nowhere near their visual penetrative thought patterns. The dry-erase cube (Kuiper, 2008) is another tool recently developed in an effort to improve student 3-D perceptions. Outcrop patterns are marked on the cube and then manipulated for VPA. It is dry erase because markings can be removed. The advantage of using plasticine is that younger students (13-18 years) are familiar with the material and enjoy the tactile feel. It enables students to hold and look all around the structure from any 3-D angle. But they can only 'see inside' with VPA. The material can be easily moulded into different shapes with varying complexity of structure and easily cut along planes of different angles. Respondents are required to listen to verbal instructions.

8.5 New Zealand Year Nine (Aged 13 years) Responses

The origin of the central rectangular pattern by Year 9 students for the longitudinal section puzzle is difficult to explain. It seems that students do not 'close' the lines they draw because of uncertainty or perhaps lack of perception as to where the boundaries go, so by drawing a circle or a rectangle in the centre, all options are covered and they therefore are not at risk of "being wrong" (e.g. Figure 8.11). It may also be caused by misperception of the cross sectional ends of the model as they are exposed to full view and often closely looked at by respondents before drawing their answers. In this case, the cross section becomes the answer because this is all the respondent sees. A large proportion (38%) of Year 9 students drew a central horizontal strip. This perhaps indicates that students recognised the need for a colour to go along the length of the model but had no idea where to put it. In short, the majority of Year 9 students (aged 13) were unable to visually penetrate a longitudinal section. Intriguingly, Year 9 respondents were also unable to perceive the correct relative proportions of the upper blue layer (strata) and the lower red layer. That is, they seem to be unable to perceive that the upper blue layer is very much thinner than the lower red layer.

Responses to the cross sectional 'puzzle' show that 33% of the Year 9 responses were correct with 53% drawing a central area surrounded by the 'outside' blue layer. This outcome is despite the fact that the correct pattern is exposed at each end of the model. It seems that this sample of students were unable to perceive that the inside pattern was going to be the same as that exposed at the ends. Most Year 9 students in this sample could not visually penetrate the model. It is also difficult to understand why some students divided the cross section into quadrants and halves. Perhaps these students did not fully understand what was meant by a cross section and simply made up an answer based on the cut marks they saw on the outside surfaces or just drew 'a cross'. Either way, these students were clearly unable to visually penetrate the structure, or, in Kali and Orion's terminology, were "non penetrative" in their answers, and indeed, many were unable to even translate the exposed ends of the model to being the same all the way through the model. Kali and Orion's study only investigated grade 12 (age 16/17years). Students were reliant on verbal instructions of what they had to do and no clues were provided by 'opening' the model before drawing their diagrams. The students who drew central circles were also unlikely to have perceived that the red 'inner' layer extended to the bottom. It seems that many of the Year 9 students simply visualise "a blob of colour" with no boundaries.

The diagonal section puzzle for Year 9 students proved to be a more formidable problem with less than 30% being correct and 23% drawing a horizontal strip for the cross section puzzle. Only two students (11%) copied the outside diagonal surface cut and 35% of this age group appeared to have little idea and simply copied what they had done for the cross section. It seems that 'lifting the lid off the top' of the model and when cut on a diagonal is too difficult to visually penetrate. Even when asked to draw or describe what the inside pattern would look like when cut horizontally along the length of the model, these younger students were unable to visually penetrate. The added complication of a diagonal cut was too difficult.

8.6 New Zealand Year Eleven (Aged 15 years) Responses

The percentage of correct responses for each 'cut' of the model is summarised in Table 7.1 in Chapter 7. Year 11 students have similar difficulties to all other age groups for visually penetrating the diagonal cut but appear to be more visually penetrative than their young colleagues for the longitudinal and the cross sections. It is still somewhat surprising to me as an experienced teacher that 15/16 year olds cannot easily transfer on inspection, the exposed cross sectional ends of the model to the unseen inside. Only half of this sample was able to do this. Year 11 students in this sample are effectively no different in their response than all other year levels. Similarly very few students are able to correctly penetrate the diagonal cut, the main difficulty being the inability to know where the boundaries 'begin'. For example, (Figure 8.9), the most common error was to not take the inner layer to the right hand edge of the model but rather to enclose it as an inner rectangle. Curved boundaries of the diagonal and cross section are rarely drawn. Note that the sides are splayed out and not straight.

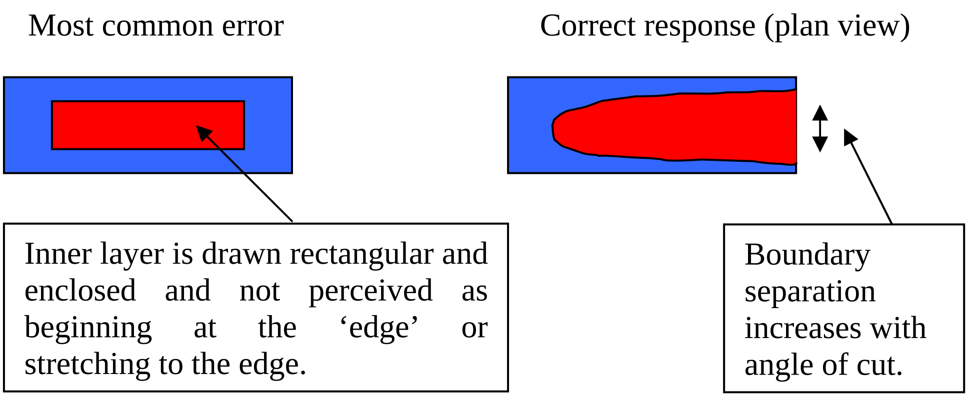
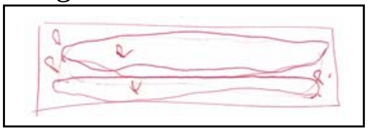
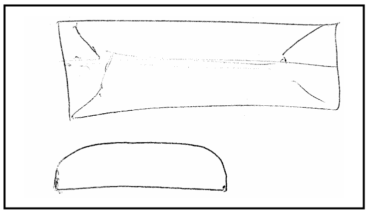


Figure 8.9. The diagonal cut response (The fold is horizontal).

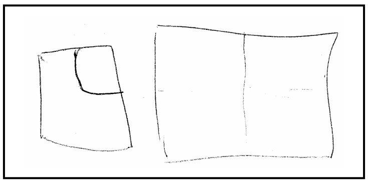
Kali and Orion's work was concerned with Israeli grade12 students. These students are the equivalent to New Zealand Year 13 students aged 17/18 years and in their final year of high school study. Although only 6 teachers (both mathematics teachers) agreed to complete the VPA cross sections, only one out of six cross section responses were correct. The scans below (Figure 8.10) show common secondary school teachers' responses.

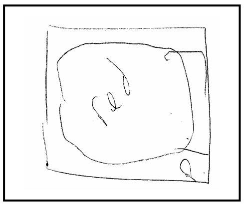
A. Longitudinal section



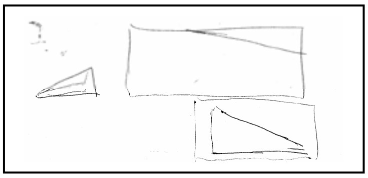


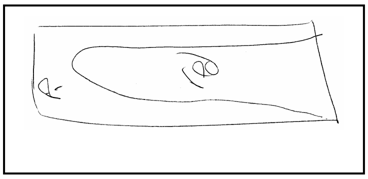
B. Cross section





C. Diagonal section





A correct response

Figure 8.10. Typical graduate teacher responses to 3-D model problems.

Although only six adult teacher responses (three female and three male) were recorded, these responses suggest that even adults without experiences and practice (one was a PhD holder) have difficulty visually penetrating the hidden structure pattern. Their responses when shown the pattern by actually cutting the model was the same as their students: *"I thought it was like that but wasn't sure"*. The scans above indicate that like their students, they search for clues to the inside pattern from the observable outside pattern and fail to visually penetrate. The best performed group were the Year 12, 16/17 year olds for the cross section. Most were able to grasp the visual connection that the exposed end of the model was the same as taking a cross section through the middle. The teachers were not confident about this and were well off the mark for all other sections. The incorrect teacher response for the diagonal section indicates a common approach to visual penetration tasks: *"copy a side that can be seen and don't worry about the invisible inside"*. For the diagonal cross section it is an important visualisation that the fold curvature generates boundaries that are **not parallel.** As the angle of cut increases, the degree of boundary separation increases, but most responses for all age groups draw parallel boundaries. For the diagonal cut, only 13/43 (33%) of all responses from age 13 to 60+ were correct. The diagonal section is the equivalent of GeoTSAT question 8a, where visualising the effect of angle change (the apparent view) on two surfaces is required. All age groups were similar in their spread of responses: visual penetration ability is much the same across all age groups in this small study. Visualising hidden patterns through three axis changes is a complex task with little or no training! Little wonder that second year geology students of age 20-23 years have difficulty forming the necessary neuronal pathways when exposed to stereonet analysis of fold structures and kinematics. With a little bit of appropriate genetics and lots of valid and structured VPA training exercises, practise makes perfect.

8.7 Comments on Verbal Responses to the 3-D Model VPA Exercise

When respondents were asked if they would like to take part in a piece of research for learning about geological structures, very few refused point blank and those that did were curious to know what was involved and were prepared to *"give it a go"*. Respondents were verbally told as clearly as possible what they were required to do. They were shown the plasticine model, allowed to hold it and look at it and then asked if they would draw the hidden structure when it was cut along the demonstrated sections. At the end of the exercise, the model was actually cut open and the respondent shown the answer: an advantage of using the plasticine model (even if it was a very simple two strata fold). The fold asked to be visually penetrated was an anticline, but it would have been possible to invert it and use it as a syncline. Actually cutting the model and having 'a look inside' was always appreciated and usually met with exclamations like, *"Ah, so that's what it is like"* or *"I was wrong then!"* or *"I got that right"*. A box was drawn for them to put their answer in for the longitudinal and diagonal sections but not the transverse section as this was thought to provide too much direction and would not allow them to show that they realised the transverse section was the same as the ends and so was more square in shape.

Respondents were told that for the diagonal section they were to draw what the pattern would look like in plan view or looking down on top of the surface when the cut section was removed. This was demonstrated to the students so it was clear what they were to draw. In some cases it appears that respondents forget that they were to draw the plan view for the diagonal cut, and simply drew the diagonal side view cut in much the same way as in the GeoTSAT instrument (Appendix 2), when faces are simply copied onto the completion face. Mentally rotating the side view to the hidden top view provides a challenge for many and across all age groups. In nearly all cases there was a verbal show of lack of confidence in being able to do the task correctly. The teachers were the most verbal at expressing before they even started how they would not be able to do it because, for example, *"I have never been any good at this"* or *"what if I get it wrong?"*

Recent work by Kastens, Agrawal and Liben (2009) report on the reasoning processes that geologists and geology students undergo when confronted with field scale outcrops. In Kastens et al study (2209) there were no folding or faulting complexities: just a simple two strata structure spread over several 'outcrops' artificially buried and in which participants were required to eventually visually penetrate. This begs the question 'does VPA direct object identification, does object identification come before VPA or both equally? As similar to responses recorded in this investigation, there appears to be an age independent and a common approach of using given, observable features as the response rather than individuals developing and using their own spatial approach. This is rather like students rewording given information in an examination question and using this as their answer rather than using individual application of observed evidence. This approach was common in the VPA problem solving across all age groups.

8.8 Summary

Not only is there much to be learnt about how students develop their spatial literacy but VPA is an emerging spatial skill research topic (King, 2006; Liben, Christensen, Kastens, & Agrawal, 2008; Liben, Kastens, Agrawal, Christensen, & Myers, 2009), VPA is required in many fields such as chemistry, engineering and medicine, but VPA is especially important in the geological sciences where so much of the 'rock evidence' is hidden. Geological deformation carries the story of geological change. Mental rotation is not VPA. Rather VPA requires the individual to mentally 'explode' a structure and to visualise the hidden continuation of stratal directions when viewed from a variety of unusual angles.

In this small study, the overall conclusion is that although the type of error made in VPA is much the same across all age groups VPA does tend to increase with age (Figure 8.11); but not simply.

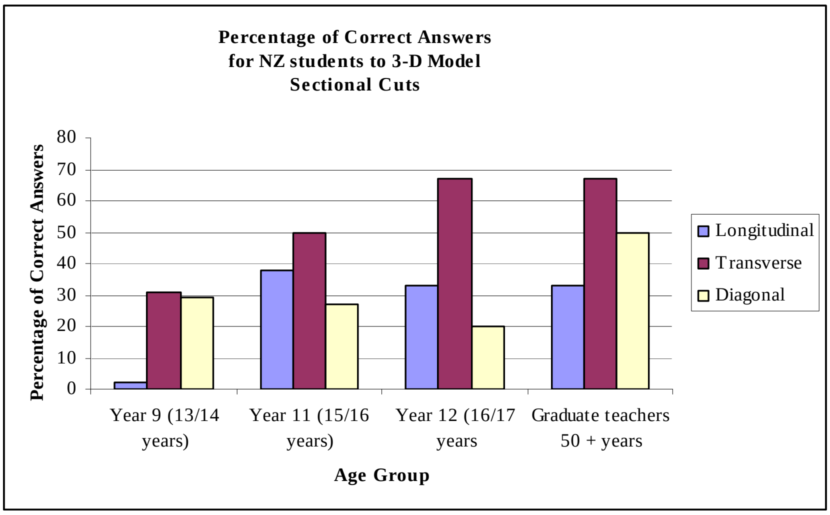


Figure 8.11. Summary of correct responses to sectional cuts.

The youngest age group was very weak at visualising the longitudinal section but from age 15 years onwards there was no difference in the percentage of correct answers. Graduate teacher responses were only better than the Year 11 students for the diagonal cut which required a higher degree of VPA experiences. Males also tended to outperform females in this study, although Titus and Horsham (2009) found that in their study there was no difference in VPA but there was for mental rotation. In support of Kali and Orion (1996), incorrect answers commonly indicated the copying of an exposed block diagram face.

Findings are tantalising and point the way for further in-depth research with larger samples to tease out what processes are operating for VPA and how novice learners and practicing geologists develop their VPA skills. Kastens et al. (2009) and Liben et al. (2008) have begun this task.

Investigating how visual-spatial reasoning is involved in interpreting geological maps is an area of rich future research. Future VPA research would also benefit from the development of a set of graded, structured puzzles that would gather information about intervention strategies across different age groups.

CHAPTER NINE

NEW ZEALAND – A CASE STUDY
THE STATUS OF GEOLOGICAL SCIENCE IN A NATIONAL CURRICULUM

9.1 Introduction

In tomorrow's precarious world, an educated population would significantly benefit from scientific knowledge and understanding of earth materials, geological processes, geological history, natural hazards and the evolution of life. The study of the fossil record is a cornerstone of geological science and is also intimately linked with understanding biological evolution. These topics and their subdivisions are fundamental to the study of geological science within any Science curriculum. Turner and Frodeman (1996) and Cooray (1996) clearly outlined the vital and unique values that the Earth Sciences bring to a student's developing scientific literacy. A poignant summary by the American Geological Society (after a century or so of Earth Science education in American curricula) on why Earth Science is important indicates what kind of role the study of Earth Science has in our Society and schools. However, the mechanism of implementation on global (and local) scales is ultimately left up to the educational practitioners.

> *To ensure a scientifically literate society, one that maintains wise stewardship of Earth's precious resources, the American Geological Institute, in co-ordination with its Member Societies, endorses the National Research Council's National Science Education Standards (1996) and agrees that Earth science should be: included as part of the science curriculum at all grade Levels, offered as a core credit science course for high school graduation and assessed through state-mandated science tests and exit exams. Ultimately, however, the future lies in the hands of students, parents, grandparents, teachers, school administrators, school board officials, and politicians at all Levels of government.*
>
> *The future of Earth science literacy—indeed, the future itself—lies in your hands.* (http://www.geosociety.org/graphics/eo/Why_Earth_Science.pdf).

These sentiments about Earth Science education are universal and are especially relevant to New Zealand for the current major revision (2006 to 2009) of the national Science curriculum, where Earth Science in the form of *"Planet Earth and Beyond"* may provide unique and essential learning experiences for the 21st century citizen. Will this learning opportunity still be there in 100 (5000?) years time?

One consequence of diminished Earth Science curricula (and political, global and local environmental concerns) has been the development of *Earth Systems Science* in an attempt to connect science, technology, society and environmentalism within a scientific framework (Hafner, 2000; Mayer, 1995; Mayer, Kumano, & Fortner, 1999). The result has been to conceptually change reductionistic Science (via traditional British hierarchical subject thinking) to one of inductionist and holistic with values and Earth guardianship at its core (Smith, 2004). Earth Science education internationally struggles for survival (See Chapter 3) not only in schools but also in colleges and universities (Akhatar, 1996; Sharma, 2003). National enrolment numbers for Geology in Australian secondary schools, for example, had declined to just over a thousand by 1998 and as a result geology became connected to 'environmental science', but in a very different and applied form (Dekkers & De Laeter, 1997). Key issues of teacher training, curriculum development and assessment directly impact on the way (or not) Earth Science is taught, learnt and valued (King, 2001, 2003). These are as relevant globally as they are to the New Zealand curriculum. This chapter needs to be read in conjunction with Appendix 3.

9.2 A Guide to the National New Zealand Science Curriculum

In the New Zealand curriculum, achievement aims provide the contextual details of achievement objectives. These objectives effectively control (along with assessment standards) what is actually taught in the classroom. This chapter provides details of the Geological Science and evolution related objectives. The 2007 NZ curriculum is available online at http://nzcurriculum.tki.org.nz.

In essence, the science curriculum is one of several essential learning areas that provide opportunities for developing a student's world view from a scientific perspective where science is seen as a way of investigating, understanding and explaining the natural world. The geological sciences are recognised within this framework. A key element is the integration of ideas about the nature of science across all ages. The conceptual basis for the curriculum, however, remains historically connected to reductionist science through the separate subject disciplines of physics, chemistry, biology, astronomy and geology. Unlike physics, chemistry and biology, neither geology nor astronomy can be studied as examinable 'stand alone' yearly subjects in the national qualification framework from Year 11 onwards. Rather, geology and astronomy are selected for study by schools as a part (or 'strand') of Science and driven by the perceived need for the gaining of credits in high stakes pre-requisitional national examinations known as the National Certificate of Educational Achievement (NCEA).

The achievement objectives and their detailed achievement aims for science education are presented in five strands across all levels and is shown in Table 9.1.

Table 9.1 The 2007 (November) New Zealand National Science Curriculum.

Achievement Objective Strands	**Achievement Aims**
The Nature of Science	Understanding about Science; Investigating; Communicating; Participating; Contributing.
The Living World (Biology)	Life processes, ecology, **evolution**.
Planet Earth and Beyond (Geology and Astronomy)	**Earth System; Interacting Systems; Astronomical Systems.**
The Physical World (Physics)	Physical Enquiry; Physics concepts; Applying physics.
The Material World (Chemistry)	Properties of materials; Chemical reactions; Particles.

What teachers teach in the classroom is controlled by the curriculum and this in turn impacts on the conceptual development of students (and also teachers). Perhaps more crucially, it influences the numbers of students who are engaged in learning geological science. Providing school courses with sufficient resources (trained and qualified staff, materials, and funding) is often dependent on the numbers of students participating and if numbers are low, resources are more difficult to justify. Most (if not all) teaching and learning is directed towards the gaining of qualifications and, as a consequence, assessment tasks (which are derived from curricula objectives) effectively control what teachers teach. If funds, resources and teachers are in short supply (very common), negative selection pressure reduces those subjects with the fewer numbers of students and also those perceived to be of less value. These 'fringe' subjects like geology and astronomy are the first to be questioned for their viability as well as their scientific usefulness. Indeed, the status of Astronomy (along with Geology) in the New Zealand curriculum is precarious (See Figure 9.1). Geology and Astronomy in the current New Zealand curriculum are lumped together under the *"Planet Earth and Beyond"* strand of the national Science curriculum. In 2006, the percentage of candidates enrolled in Geology and Astronomy were both less than 15% of all candidates enrolled for Level 1 Science standards both declining compared to Physics, Chemistry and Biology. It is notable that for the initial examinations for the National Certificate in Educational Achievement (NCEA) in 2002 Geology enrolments were higher than Biology but declined rapidly after this (Figure 9.1). Why is the number of candidates for the *Planet Earth and Beyond* strand declining to below 15% of all candidates at a time when a greater understanding of how our planet functions is needed? This is especially so in a country waiting for the next magnitude 8+ earthquake.

The initial decline may have been a consequence of poor results and schools subsequently choosing not to offer Geology, especially if it was perceived that students were less likely to be successful in comparison to other science standards. This decline may also reflect teaching competence with few trained and qualified teachers of the Earth Sciences (Lee, 1995) and teacher training issues, resourcing and historical values attached to the subject. Prior to 1993, geology as a separate subject of national assessment did not exist, so the infrastructure and traditions were never firmly established in secondary schools. Indeed, geological science was not included in the Science syllabus of 1968 for Form 5 (age 15/16) but was included for Years 9 and 10 (first two years of secondary school ages 13 and 14 years) as "The Earth's Crust".

> *"11.1. Simple survey of the geological history of the school district. Fossils as evidence of evolution and change. Formation of coal and oil; accumulation of mineral deposits. Landscape as the current expression of natural agencies on the Earth's crust e.g., weathering, erosion, volcanism and earthquakes". (Department of Education, 1969, p.16).*

Plate tectonics was in hot debate at this time, but in this syllabus there was an aspect (Section 12) on "Man's use of the Earth's resources". As a consequence of this syllabus, teaching geological science was uncommon in secondary schools until the introduction of the 1993 Science curriculum. Geography was about surface features.

The candidate numbers for NCEA Level 1 Science examinations are shown in Figure 9.1. With the current four strands to the national Science curriculum an equal spread of teaching time around 23% to 27% of candidates per strand would be a reasonable expectation. All data excludes those students who are enrolled in the national correspondence school.

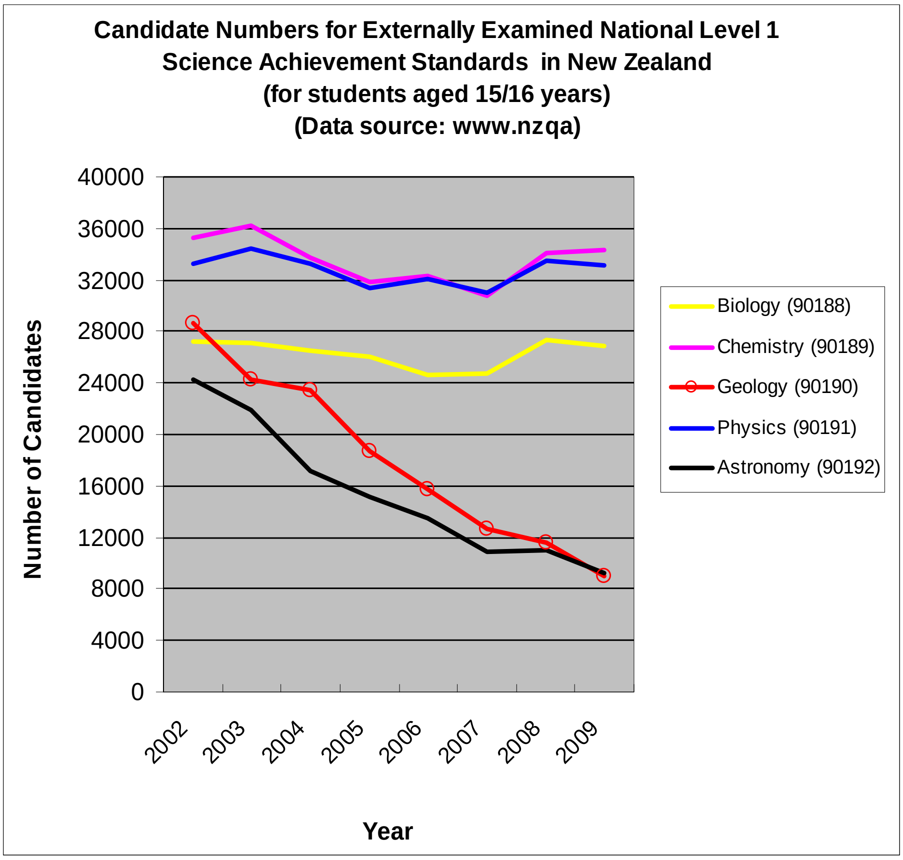


Figure 9.1: Candidate Numbers for NCEA Level 1 Science (aged 15/16 years).

9.3 Aims of this Chapter

Research Question 1 asks: What are the characteristics of international Geoscience curricula and their implementation, with particular case study reference to the New Zealand curriculum?

This chapter focuses on national assessment tasks and curriculum issues in New Zealand as the drivers for the teaching and learning of Geoscience and evolution. Evolution (in terms of the micro/macro/ molecular fossil record, and mechanisms) is fundamental to the learning of Geology and Biology and illustrates an important juxtaposition of subjects neither of which (arguably) are sufficiently taught in the New Zealand curriculum. Biology in particular is dominated by Mendelian genetics, DNA, cell structure and function and ecology. It appears that evolution is a minor part of a student’s learning in Biology despite it being the reality concept that makes sense of living (and extinct) things. Paleontology is not examinable. In the 2006 NCEA Level 2 Biology assessment suite (composed of five achievement standards), evolution questions comprised 7% of the total (3 questions out of 42). This chapter also describes the relevant standards that have been developed in New Zealand for these two subjects.

Assessment opportunities enable learners to demonstrate authentic levels of knowledge, thinking and comprehension. In comparison to other traditional science subjects (Physics, Chemistry and Biology), earth science and evolution assessment opportunities are limited, with geological science especially, in continuous decline (Figure 9.1). This decline in candidate numbers for geological science is significant and the main reasons are historically, politically and resource based.

9.4 Historical Perspectives

High stakes national summative (qualification producing) assessment in New Zealand has undergone a revolution in the past decade. The New Zealand Qualifications Authority (NZQA) was established in 1990. A national assessment system has moved from norm referenced ranking by external examination (from 1936 to 2001 via school certificate, university entrance, bursary and scholarship examinations and based largely on British hierarchical thinking), to standards based (SBA) or criterion referenced assessment (CRA) with the introduction of a new national assessment certificate in educational achievement known as the NCEA in 2000. NCEA operates under the national qualifications framework (NQF). The highest Level examinations at secondary school are scholarship examinations and provide a means of identifying high achieving critical thinkers in their final year (Year 13) of secondary school at the age of about 18 years before entering university. Scholarship examinations are administered by NZQA and undergo a rigorous 'triangulated' system of setting, marking, critiquing, moderating and revising. The vast majority of final year secondary students sit what is called NCEA Level 3 in various subjects both internally (i.e. set by individual schools, and moderated by NZQA) and externally (set and managed by NZQA).

Movement to criterion referenced assessment has not been a painless experience, politically, philosophically nor practically, but nonetheless is now firmly established as the New Zealand qualifications system. A detailed review report commissioned by NZQA (Zepke, 2005) evaluates the impact of SBA on many aspects of teaching and learning. Along with workload issues and moderation, the creation of a single, national qualifications framework that is standards based remains controversial (Alison, 2007; Hipkins, 2010; Lee, 2001; Philips, 2003). No doubt, the introduction and evolution of SBA for secondary schools will show in the future (if not already), an excellent example of how conceptual change actually occurs.

9.5 School Deciles

In New Zealand, decile ratings (derived from national census data) are very broad socio-economic indicators of deprivation which are used by the Ministry of Education for operational funding of schools. Schools with low decile ratings are provided with more funding than those with higher ratings. In January 2005 the ethnicity factor (proportion of students in schools of Maori and Pacifika origins and English for Speakers of other Languages) was removed from the decile rating criteria. Although school deciles are incomplete measures and potentially misleading they do provide a reviewable and statistically representative snapshot of the socio-economic status of a schools population. There are two important limitations of the assigned decile ratings (Johnston, 2005):

1) They are blunt and broad indicators for entire schools and do not predict an individual student's socio-economic circumstances.
2) They provide no information about the distribution of socio-economic dynamics in an individual school's student population.

Schools are able to apply for review of decile ratings if there are perceptions of significant social change. Examples of this may be an increase in overseas immigrant workers contributing increased numbers of students into a school or loss of school age families from a mesh block. Mesh blocks are geographic census data gathering areas of about 70 households. Any achievement comparisons of schools and regions need to take into account this decile indicator because student performance is correlated to socio–economic status. Deciles used in this thesis do not include ethnicity as decile data were derived from the 2006 Ministry of Education's schools directory statistics data (www.minedu.govt.nz). Nonetheless, there are clear links between ethnicity, socio-economic status and achievement (Johnston, 2005; Lillis, 1999; Ministry of Education, 2009). Schools (Secondary and primary) with more than 120 students require a random sample of the total roll for gathering information in assigning a decile rating. Ethnicity data was removed from decile calculations in 2007.

School deciles are calculated from the following criteria:

- Household income - percentage of households with income in the lowest 20 per cent nationally.
- Occupation - percentage of employed parents in the lowest skilled occupational groups.
- Household crowding - number of people in the household divided by the number of bedrooms.
- Educational qualifications - percentage of parents with no tertiary or school qualifications.
- Income support - percentage of parents who received a benefit in the previous year.

Statistically representative data for these criteria are gathered from small geographic contributing areas called mesh blocks (60-100 households).These mesh blocks often correspond to suburban areas in towns and cities. Representation is based on the size of school with usually 300 student addresses which are then plotted onto the mesh block locations. From here, census data using the criteria above for each household is used to assign a school decile. It is important to note that a decile rating does not reflect the total distribution of socio-economic circumstances within a school; it represents the proportion and degree of social deprivation of students in a school. Schools are ranked separately for each indicator and then the rankings are summed for each school to enable government funding allocations. Any meaningful comparisons of school achievement data should be from the same decile ratings. Each school is part of a larger geographic region such as Canterbury or Auckland or Wellington or Westland. Figure 9.5 in Appendix 3 shows the geographic locality of these educational administrative regions in New Zealand to provide a 'spatial' locality map for regional data shown in Figures 9.1, and 9.12 in Appendix 3. The total population of New Zealand, barely the size of a large state city, was around 4.4 million in 2009 and only about 850,000 people in the whole of the South Island, NZ: a very small country with only 434 secondary schools of various kinds.

9.6 School Deciles and Targeted Funding

Decile ratings are importantly related to central government funding: the lower the school decile the greater the funding per student. Targeted funding is intended to reduce the impact of high social deprivation on student achievement through increased resourcing. Figure 9.2 shows the relationship between funding types and school decile ratings. Exactly how this increased funding is spent by schools, and its effectiveness on improving academic achievement (presumably by measuring increases in results gaining credits for NCEA assessment standards) in low decile schools (deciles 1- 3) has yet to be shown. Evidence for 2005 geoscience assessment results suggests that increase in funding for low band decile schools has had no effect on educational achievement (Figures 9.2 and 9.3).

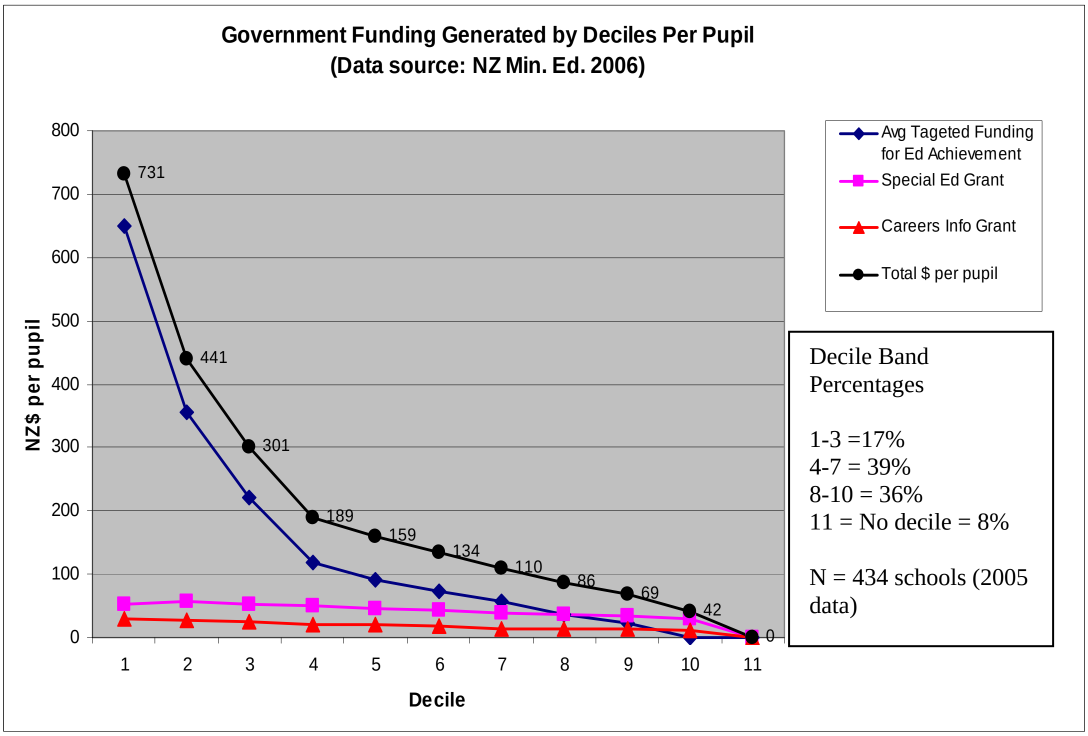


Figure 9.2. Government funding allocation per decile (2006 data)

Although subject to change, there are essentially three funding types that are generated directly from school decile ratings: targeted funding for educational achievement (TFEA), special education grants (SEG) and careers information grants (CIG).

Figure 9.3 indicates that as decile rating decreases, the funding exponentially increases. 17% (Decile band 1-3), of all secondary schools having generated results that gained credits in geoscience assessments for 2005 received an average TFEA of $375.64 per student with middle band decile schools receiving an average of $84.60 per student. In other words, low decile band schools receive on average of just under 4 times the amount of money for educational achievement as do deciles 4 -7 schools. Although funding for SEG and CIG are quite low per student, low decile schools do receive more per student. When educational achievement in the geosciences are compared to the targeted funding regime (See Figure 9.4), it is clear that receiving 3.75 times more money per student than mid decile schools, this funding does not appear to be directly effective.

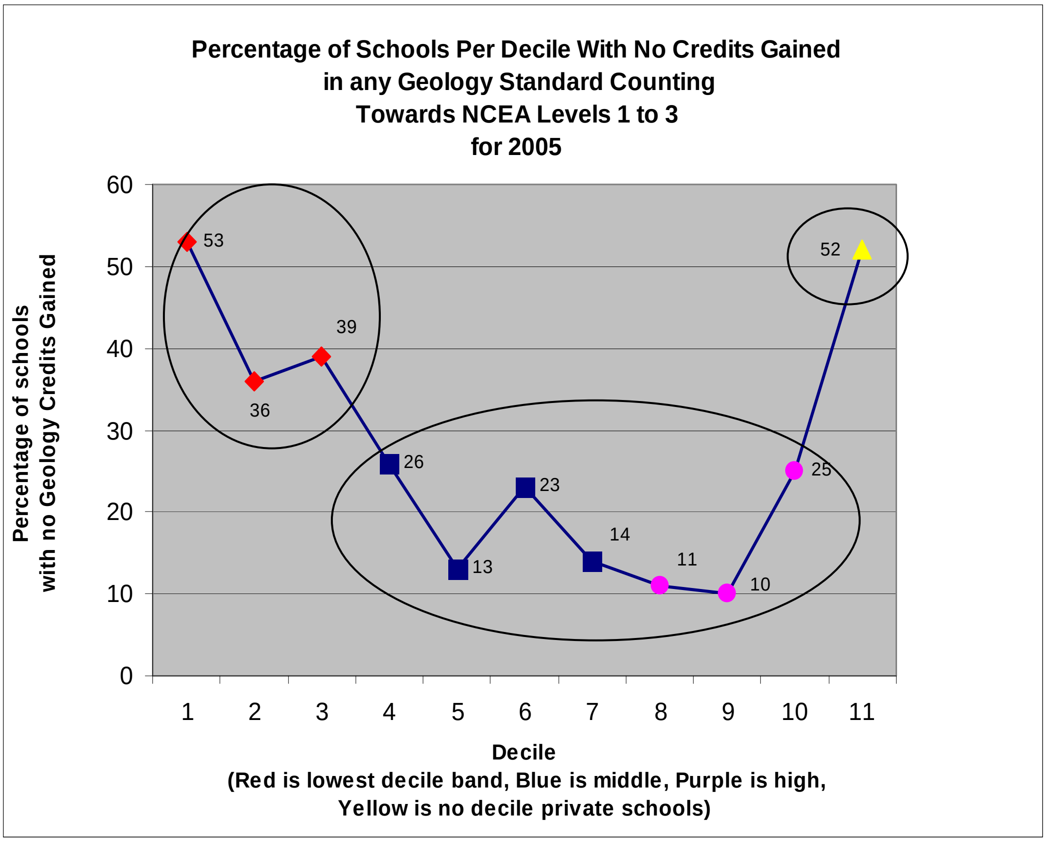


Figure 9.3. School deciles and achievement in **Geoscience** assessments.

Figure 9.4 shows the percentage of NZ secondary schools (N = 434) for each decile which **did not** gain credits in geoscience assessment tasks for national frameworks qualifications at Levels 1 to 3 in 2005. On average, 43% of low band decile schools, 19% of mid band decile schools, and 15% of high decile schools did not record any credits in geoscience for 2005. In this respect it is somewhat surprising that private schools are similar to decile one schools but this might reflect the fact that many of these private schools do not offer any geoscience standards for assessment, rather than reflecting a lack of student achievement. In fact regional data supports this (See Figure 9.10). The teaching of geology has not been a traditional teaching subject and is therefore still not taught. It is notable that as a result of widespread concern about how examination results are recorded, from 2007 onwards, failure rates are recorded in national school statistics for both externally and internally assessed standards (www.nzqa.govt.nz/news/info/ncea-improve-bkgrnder.doc). Internally assessed achievement standards are scientific investigations and research tasks.

NCEA standards-based assessment was introduced in 2002. Figure 9.4 shows the historical changes in the number of candidates gaining credits per school decile for the Level 1 NCEA geology standard AS 90190: *"Aspects of Geology"*. This is a key standard because it has the highest number of candidates in a geological science related assessment task at secondary school (See Figure 9.1). Historically, decile one schools (and private schools) have always had low numbers of achievers in this standard, but deciles 2 and 3 schools (after an initial boost in 2003) show significant decreases from 2004. Did these schools 'try out' AS 90190 in 2002 and then find it to be too difficult for the majority of their students? Did many schools perceive after 2003 that there was little point in pursuing a subject in which few students could achieve excellence and/or merit, and in so doing reduce the "pass rates' and hence a perceived reduction in school status and competitive 'quality? If so, why? Do Science departments really have the expertise, resources and energy to persevere with teaching geological science? Why have decile 5 schools recorded the greatest decline in candidate numbers in 2005? Although there are general trends of decline across all deciles, decile 9 schools have shown increases until 2005. Research needs to be carried out on why it is that unit standards and NZASE standards are increasing at the expense of achievement standard 90190 *"Aspects of Geology"*.

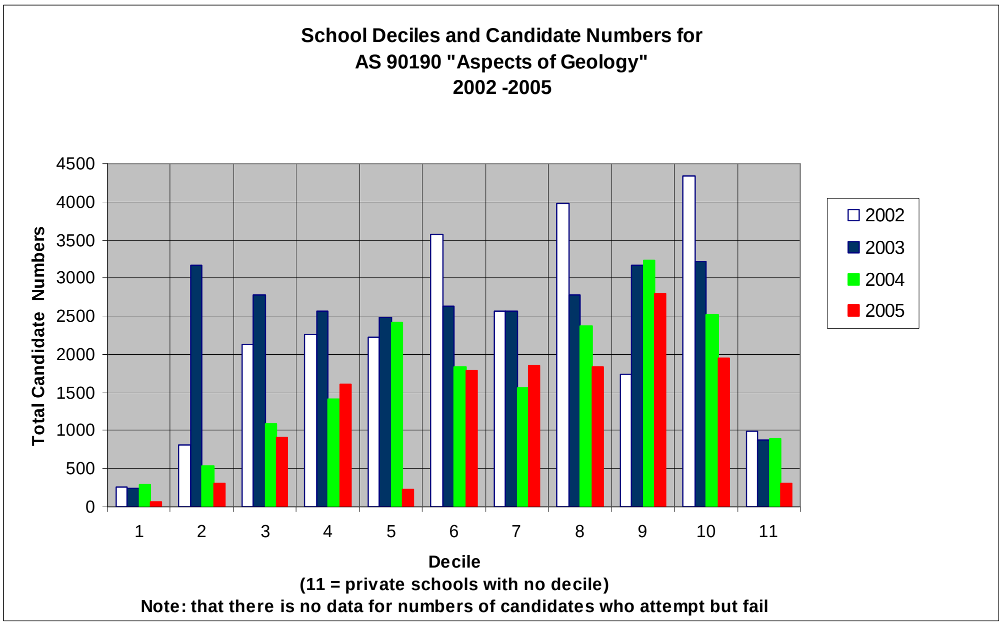


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Figure 9.4. School deciles and candidate numbers for AS 90190 *"Aspects of Geology"* as represented by results gaining credit (RGC): 2002 – 2005 (N = 434 schools).

To place this case study in perspective, Table 9.2 shows the percentages of school decile banding of secondary schools in 2006 (and in schools where national qualifications in earth science are recorded), compared with the decile banding proportions for the total number of schools on record. Figure 9.4 shows the mean percentages of each school decile recording results gaining credit (RGC) in the Earth Science assessment standard. Data are sourced from the school directory of the NZ Ministry of Education. The secondary schools data used in this case study have similar broad decile band proportions to the total NZ school population (but prior to readjustment post 2006). Decile 8 schools form the highest proportion of secondary schools, receive the third to lowest funding allocation per student (Figure 9.2) and along with decile 9 schools outperform all other schools for results gaining credits in Earth Science assessment standards (Figure 9.3). Deciles 4, 6 and 10 schools are similar in performance with decile 10 schools not receiving funding for educational achievement specifically generated from their decile rating. Private independent schools (11 on Figure 9.4) do not receive government funding and have much lower numbers of students gaining credits. This reflects the fact that few of these schools offer their students AS 90190 as an external examination.

Table 9.2 Decile Band Comparisons in 2006

Decile Bands	**All Primary and Secondary schools (N = 2597)**	**Mean Percentage of Secondary Schools per Decile (N = 434)**
1 – 3 (low)	***30%*** (27%)	1 = 4%
4 – 7 (middle)	***38%*** (43%)	2 = 7%
8 – 10 (high)	***30%*** (25%)	3 = 6%
11 = Private schools with no decile.	***2%*** (5%)	4 = 7%
	This study N = 434 secondary schools.	5 = 11%
		6 = 10%
	Bold italics = **2006** school directory data for all NZ schools (primary **and** secondary) where N = 2597.	7 = 11%
		8 = 14%
		9 = 9%
	(Rounded percentages)	10 = 13%
		11 = 8%

(Note: As from 2007 decile ratings were readjusted to around 10% at each decile but data presented is based on the 2006 data. The percentage of Maori students in schools for example was removed from the criteria for decile calculations. However, what changes in individual school deciles that have occurred are not likely to significantly impact on conclusions).

9.7 Unit Standards and Achievement Standards

Unit standards and achievement standards are the current styles of national assessment examinations (up until 2010, when unit standards will be removed). This section describes what these standards are.

Student evidence of understanding and knowledge is evaluated against written criteria called achievement standards or unit standards and given a credit or point value. Unit standard assessment tasks are administered and often set by an individual school but they do not identify or assess Levels of understanding. It is an assessment task that is either achieved or not with moderated provisions for reassessment. Unit standards operate through the use of elements and performance criteria that define the standard. An example is shown below for one element of US 18982 “Demonstrate Knowledge of Earth Science”. This particular example is from the New Zealand Association of Science Educators (NZASE) unit standards and is derived from curriculum Levels 4/5 (for lower ability students in Year 11). It carries two credits towards NCEA Level 1 but critically, does not permit students to advance to Years 12 and 13 Sciences.

Exemplar:

US 18982: ‘Demonstrate Knowledge of the Earth’ assessment criteria.

Element 1 : *Describe the structure of the Earth.*

Performance criteria

1.1 The description outlines features of the Earth’s structure.
Range: three of - mantle, core, crust, plates, volcanoes.

The introduction of unit standards pre-date achievement standards. Achievement standards are externally and internally assessed but recognise different Levels of understanding by awarding achievement as achieved (A), achieved with merit (M) or achieved with excellence (E). Regardless of quality of the achievement (A, M or E), the credit points received are the same. That is, if a standard carries three credits (as in *Aspects of Geology* AS 90190 Level 1, Year 11), students do not receive more credits if they achieve with excellence rather than merit. This fact may have an influence on student motivation especially where students are driven by and value comparative ranking success rather than achievement of criteria for excellence. Students who attend but do not attempt examinations have this detailed on their record of learning. All assessment tasks are required to be valid with reference to the criteria set down in the achievement and unit standards, be fair, where candidates know exactly what is required, and sufficient to allow candidates to demonstrate their learning. It must be appreciated that achievement and unit standards provide the criteria for assessment of only parts of the national curricula. Assessment tasks do not attempt to 'test' the whole curriculum. Students receive for example, in Level 1 Science, a three hour external achievement standard examination composed of five different papers, one for Physics, Chemistry, Biology and two for Planet Earth and Beyond. Planet Earth and Beyond is divided into *Aspects of Geology* and *Aspects of Astronomy* with the Geology generating three credits and Astronomy two credits. Time recommended to complete the Geology examination is 30 minutes. Each of the other achievement standard assessment papers in Physics, Chemistry and Biology generate five credits each. There is much debate about the validity, purpose and usefulness of credit values when criterion referenced assessment is used as well as the relationship between curriculum statements and assessment tasks (Alison, 2008; Ministry of Education, 2006). For example, the key Geology standard AS 90190 demands assessment of **selected** parts of the curriculum objectives in *"Planet Earth and Beyond"* and has been criticised for not including more of the curriculum achievement aims. Indeed, revisions of the standards in 2004 removed all assessment of the mineralogy component of AS 90190. This begs the question: "if it is not going to be assessed why bother teaching it"? Assessment standards have been constructed by Ministry of Education contracted 'subject experts' and are derived from aspects of the *"Planet Earth and Beyond"* strand of the science curriculum.

Geoscience is taught essentially within the national Science curriculum under "Planet Earth and Beyond" strand of the Science curriculum as *"Aspects of Geology* and *Aspects of Astronomy"* but there are parts of Earth Science such as natural hazards taught and assessed in Geography. Evolution (and paleontology) as sub disciplines of the geological sciences are not mentioned in the current curriculum but their study is implied within a study of geological history and correlation of rock strata.

Declining numbers of students (Figure 9.1) attempting the geology component of the *Planet Earth and Beyond* standard (about 70% over seven years) remains an important issue for the future of the geosciences in the school curriculum. Other Bio/Geoscience topics such as fossils and evolution are also taught to various depths in the national Biology curriculum and are outlined below. The national Science curriculum is currently in the first stages of revision and the impact of any revisions on Earth Science assessment is yet to be seen.

9.8 What are the Current (2002–2010) Assessment Opportunities for Geology and Evolution in the New Zealand National Qualifications Framework (NQF)?

The current national science curriculum was introduced in 1994 and assessed up until 2002 by norm referencing using scaling and percentage marks for individual student work. IN 2002 the first standard based assessments used the standard criteria outlined in the tables below. Several standards have since expired (eg US 6359 *"Measurement of Geological Time")* or undergone revision, especially the New Zealand Association of Science Educators (NZASE) certificate standards. The standards used for assessment opportunities are detailed in Appendix 3. The standards detailed in this thesis are valid and relevant to data analysis of student numbers and results.

9.8.1 General Discussion

Firstly, it is important to note that although the school leaving age is 16 years the New Zealand curriculum is compulsory only up to the end of Year 10 (second year of secondary school - about age 14 years). Internal and external theory assessment examinations only assess selected (and reviewable) aspects of the curriculum aims. External examinations are set, managed, marked and supervised by NZQA and internal assessments are managed and marked by the school. Of the internal assessments, practical investigations and research assignments are available for unit and achievement standards. Currently, the total number of credits available for assessing evolution and geology is 49 of which 30 are generated from internally assessed unit standards. At Level 1 Science, Achievement Standard (AS) 90190 *("Aspects of Geology")* has a credit value of three compared to five each for physics, chemistry and biology. The other two credits are assigned to AS 90192 (*Aspects of Astronomy*) as space science. The percent change in the number of candidates for Level 1 Science achievement standards is compared in Figure 9.6. Clearly, the percentage of candidates involved in learning and presenting for examination in *'Planet Earth and Beyond'* at NCEA Level 1 has declined in comparison to other 'sciences'. On a positive note, prior to 1994 there was only one norm referenced Science examination containing physics, chemistry and biology. There were no questions on 'Geology' and questions were predominantly descriptive with some explanation expected and none requiring a higher thinking Level of discussion and linking of ideas (Arguably appropriate and valid for 15/16 year olds). Prior to 1994 geoscience was not externally examined and generally not seriously taught at any curriculum Level. In 2008, Geology continues to show the highest percent change in numbers of candidates with Astronomy levelling off.

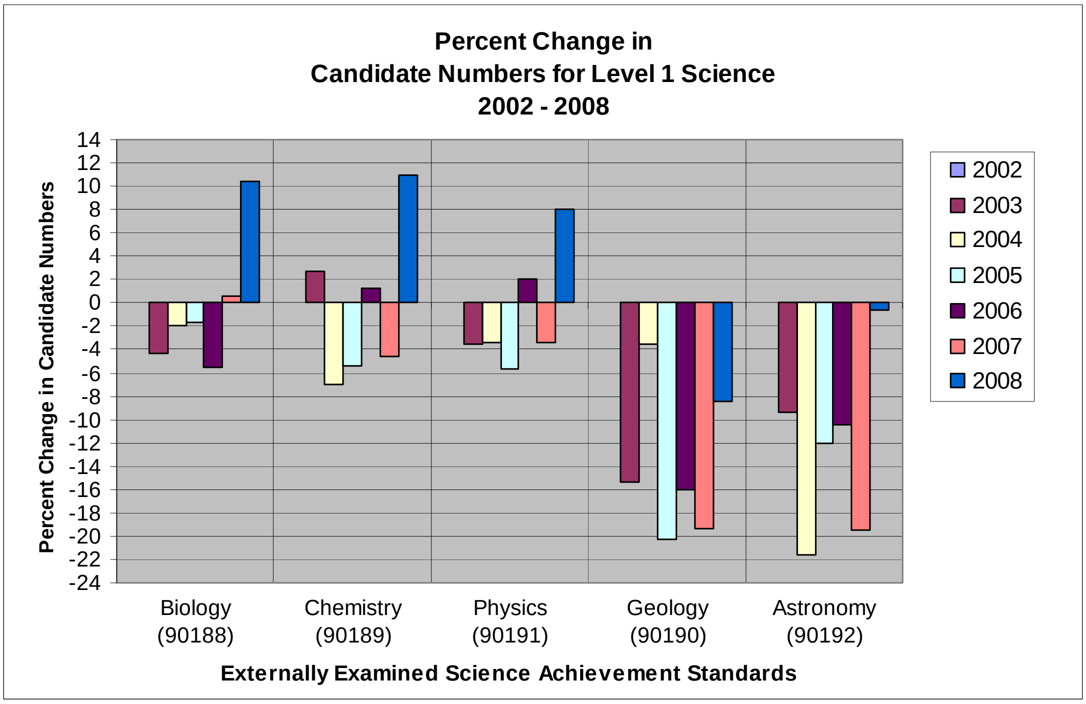


Figure 9.6. Percent change of candidate numbers for NCEA Level 1 Science.

In effect, despite geological topics under the *Planet Earth and Beyond* strand being entrenched in the national Science curriculum, there continues to be teacher training issues, infrastructure and resource issues and an increasingly selective student body which produces a steady decline in the teaching and learning of Earth Science. A significant issue is the widening gap between freedom of course choice by students and what schools actually offer because insufficient numbers of teachers are trained in the Earth Sciences and so do not understand the educational values of using for example, an Earth Systems approach to learning about our planet. It seems that the New Zealand Science curriculum is in transit from a reductionist compartmentalised Science to a holistic Science. In the race for 'league table' status, schools are unlikely to offer candidates subjects where there is less likelihood of comparative success.

Biology provides the most opportunities for learning about the fact of biological evolution, but this remains very limited until Level 3. Although the study of the fossil record is an essential part of any discussion of biological evolution, this aspect is conspicuous by its absence and minimalism at secondary school in NZ (See assessment opportunities for Geology and evolution in Appendix 3).

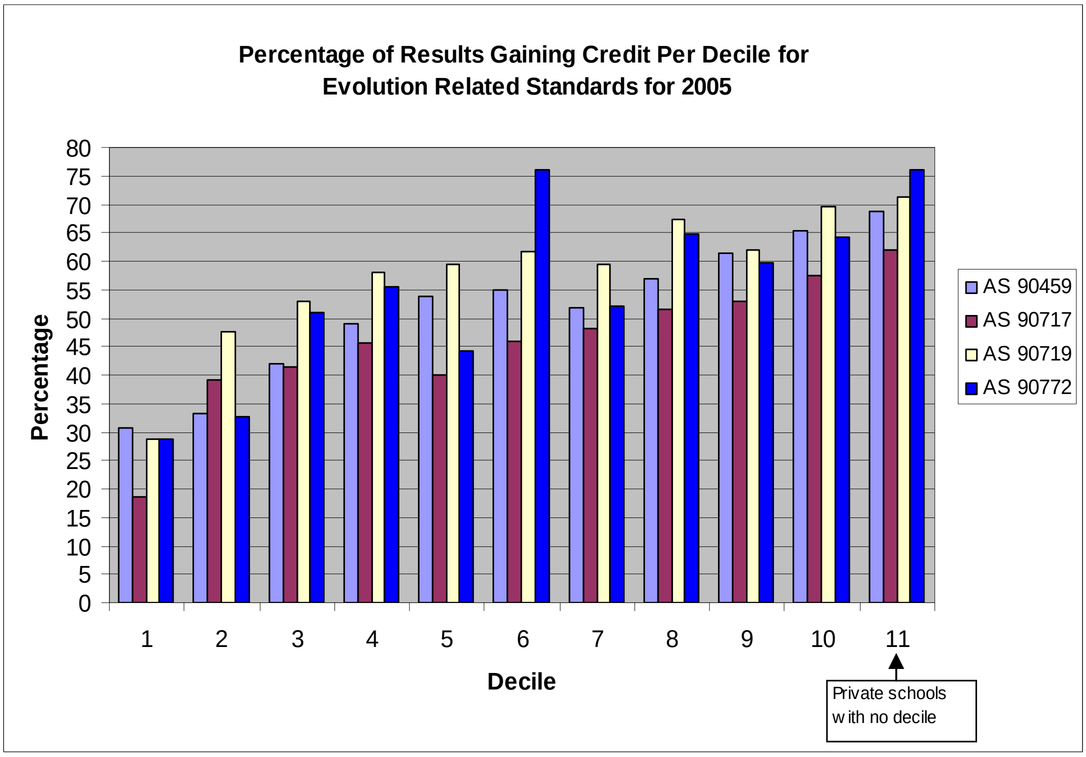


Figure 9.7. School deciles and evolution related assessment standards.

The first national examinations in Level 3 NCEA Biology occurred in 2004, but even so, the number of candidates achieving credits in *"Patterns of Evolution"* (AS

90717) and *"Human Evolution"* (AS 90719) is quite small (Figure 9.7). Figure 9.7 also shows the relationship between results gaining credit (that is, candidates who pass) with school decile ratings shows that as school deciles decrease the percentage of results gaining credit decrease but with some minor exceptions. These exceptions are likely to be related to candidate numbers. AS 90772 *("Describe the factors and processes involved in the evolution of NZ plants and animals")* is a Year 12, NCEA Level 2 and curriculum Level 7 **Science standard** and not a Biology standard. Decile 6 schools have performed well in this. Even with the revised decile distributions of 2007, lower decile schools still have lower pass rates (Ministry of Education, 2008, 2009).

9.8.2 Assessment of Evolution in the Revised NZ Science and Biology Curricula

A key conceptual change to the national science and biology curricula includes a formal recognition (in terms of externally examined achievement standards) of biological evolution (Figures 9.8, 9.9., and 9.10). In detail, however, this change is not so obvious. The following discussion outlines the relevant draft standards (for implementation in 2010 - 2012).

Current: AS 90188	**Proposed Standard B 1.3**
Has no evolution content	(4 credits, external examination) "Explain the importance of variation within a changing environment" Inheritable nature of DNA; phenotypic expression; variation and adaptation to environment.

Figure 9.8. Evolution standards for NCEA Level 1 Science (15/16 year olds).

9.8.3 NCEA Science Levels Two and Three

There are no proposed specific achievement objectives in biology, chemistry and physics standards within the national science curriculum for Levels 2 and 3, but would instead be part of achievement objectives 2.2 and 3.2 (See Table 9.3) and internally assessed. AS 90772 is removed in these draft standards. Indeed, this standard only achieved just over 500 results gaining credit in 2007 (See Figure 9.21 in Appendix 3).

Topics could be oceanography, global warming, or bio fuels. In other words, traditional science subject disciplines are replaced with a thematic/project approach that integrates scientific understandings and used to inform decision making processes about socio/scientific issues. The achievement objectives proposed for Levels 2 and 3 Science are:

Achievement Objective (AO) 2.2 (8 credits. Internally assessed)

Understand and communicate a socio-scientific issue identifying personal and societal actions

AO 3.2 (8 credits. Internally assessed)

Make informed judgments about the social, ethical, and personal implications relating to a major scientific issue / controversy.

The study and assessment of evolutionary principles, causal mechanisms and evidence at Levels 2 and 3 **Science** appears to be significantly diminished if not eliminated. Although there may be social issues with evolution, there is no scientific issue: in the sense that there is only debate over refinement of understanding. It could be argued that rather than socio scientific issues being used to help develop reflective and moral decision making (Zeidler, Sadler, Applebaum, & Callahan, 2009; Zeidler, Sadler, Simmons, & Howes, 2005; Reis & Galvao, 2009), socio-scientific issues are not relevant to Science per se, especially when the emphasis is on social dimensions and moral decision making rather than on the science. Many socio-scientific issues may also be beyond the cognitive abilities of 15 to 18 year olds, yet alone the ability of teachers to deliver. What is the difference between a scientific debate (not the emotive controversy), and a socio-scientific issue? Evolution as a scientific theory is not controversial (Scott, 2004) but the interpretation of specific evidence may be. The pedagogic complexity of using socio-scientific issues as a context for teaching science concepts and NOS deserves further research. As to be expected, biology for Levels 2 and 3 contain content on evolution but this is now proposed at Level 2, to be formalised as external assessment standards.

AS 2.5 (3 credits)	*"Explain how the interaction between ecological factors and natural selection leads to genetic changes within populations"*. Genetic changes in populations arise from selection pressure or genetic drift. Concepts include: sources of variation and how natural selection acting on phenotypes result in allele frequency changes in the gene pool.
AS 2.7 (4 credits)	*"Understand that DNA and the environment interact in gene expression"*. Concepts include: Central dogma, effect of environment on gene expression and control of gene expression **over time.**

Figure 9.9. NCEA Level 2 External Assessments of Biology and Evolution Content.

Achievement Standard (AS) 3.3 (4 credits)	*"Responses of Organisms to their environment"* Key concept is that responses are a result of evolution i.e. adaptation to the environment, selective advantage and survival in the environment.
AS 3.5 (4 credits) Note: this standard is equivalent to AS 90717.	*"Describe evolutionary processes leading to speciation"* Concepts include: brief history of the evolution of evolutionary theory such as punctuationism and gradualism, macroevolution and speciation, mutation, Hox genes, gene pools, heterozygote advantage, founder effect and polyploidy.
AS 3.6 (4 credits) Note: AS 3.6 is equivalent to AS 90719	*"Describe trends in human evolution"* Emphasis is on trends (such as culture as a dominant selection pressure rather than on specific fossils, interpretation of dispersal evidence, adaptive value of bipedalism, natural selection and patterns of evolution as related to humans.

Figure 9.10. NCEA Level 3 External Assessments of Biology and Evolution Content.

9.8.4 Discussion

Eldredge (2008) neatly points out that how evolution is thought about influences the way it is taught and incorporated within curricula. For example, paleontologists and taxonomists perceive evolution as a "taxic" change through time from a common ancestor whereas a geneticist might perceive evolution as a "permanent change in genetic information". Eldredge perceived these as taxic and transformationist in character and not as competitors but as two valid and useful ways of viewing evolution, especially when causal processes are integrated. The fact that most teachers of biology (and also biology curriculum developers), are 'genetically oriented' they tend to be transformationist in thinking rather than paleoenvironmental and taxonomic. In other words, the power of genetics viewed from the perspective of living organisms and genetic change in populations, dominates the biology curriculum because this is the dominant view of curriculum developers. This is illustrated by the achievement objective for AS 2.7. As discussed in Chapter 3, paleontology and in particular, geological time, are ‘taxic’ in approach, but is not reflected in this curriculum and indeed, has been removed.

The link between understanding the nature of science (NOS) and acceptance and comprehension of evolution has been well documented (Bishop, 1990; Brem, 2003; Farber, 2003; Leach, 1997; Lederman, 1992) and is clearly important in potentially making a difference to the way evolution is perceived. Acceptance however means different things to different cultures and individuals. In the NZ biology curriculum, the NOS strand is incorporated into all assessment standards (www. nzase.co.nz.) and provides an opportunity to develop meaningful student (and teacher) understandings of how the nature of science impacts on, for example, evolution. However, although there is significant correlation between NOS perception and acceptance of evolution, Lombrozo, Thanukos, & Weisberg (2008) accurately caution that the efficacy of this connection deserves considerably more research, especially specific aspects of NOS understandings about scientific theory and interpretation of valid evidence. Similarly, actually making a difference in the classroom is also a long way from just having appropriate connections written into a curriculum. Indeed, it is not always obvious that these NOS ideas are crucial to an understanding and acceptance of evolution, but the stereotyped views of science investigation as being ‘fair testing’ are. ‘Pattern testing’ is recognised in the NZ Science curriculum but is rarely used for assessment purposes.

9.9 NCEA Level 1 Geological Science: Unit Standards versus Achievement Standards

Although the national New Zealand Science curriculum is currently under review the assessment standard criteria used for national qualifications will not change until 2010. Unit standards (competency standards) criteria in the Earth Science and Science domains have undergone revision in 2006 but are still derived from the national Science curriculum. Table 9.3 contrasts unit standards with achievement standards. As pointed out previously, the NZASE certificate assessments are derived from curriculum Levels 3, 4 and 5 and are designed for lower achieving Year 11 students (15 year olds), whereas achievement standards and unit standards are derived from curriculum Level 6 for the same age group. Curriculum Level 6 is a NZ accepted average achievement level for students. The increase in the number of schools (Figure 9.11, Appendix 3), from 2005 to 2008 recording student credits gained from the lower NZASE standards and the increase shown for Level 1 unit standards comes at the expense of the Level 1 achievement standard AS 90190. The reasons for this deserve further investigation but are likely to involve: teacher competence issues such as lack of trained and qualified Earth Science teachers (Lee, 1995); historically lower subject status; lack of resources; lower credit value and perceived school needs to 'meet the needs of students' by enabling maximum individual credit accrual for the least amount of effort. National assessment tasks drive what is taught in the classroom.

Table 9.3. Unit Standards versus Achievement Standards summary.

UNIT STANDARDS	ACHIEVEMENT STANDARDS
Summative and formative theory, practical scientific investigations and research standards managed by the school.	Only summative and formative practical investigations and research standards managed by the school.
Theory, research and practical components externally moderated by NZQA. Exams are internally set.	Practical and research components moderated by NZQA. External exams are contractually set, moderated and managed by NZQA.
Highly likely to be the same theory exam and practical each year for each standard because of teacher workload issues.	Different and moderated exam papers each year but derived from the same criteria. Practical likely to be the same each year.
Are either passed or failed (competency based) and composed of elements (E) and performance criteria (PC).	Are achieved, merit achieved or excellently achieved. Enables students to demonstrate Level of understanding.
Sitting supervised by classroom teacher	Not supervised by classroom teacher.
Credit value of 3 points. Lower curriculum Level NZASE standards have a credit value of 2.	Credit value of 3 points
Able to be reassessed.	Not reassessed.
Do not assess the same aspects of the curriculum to achievement standards.	
NZ Assoc. of Science Educators (NZASE) assessment tasks are commercially available.	Students pay an entry fee. Papers are not purchased.
Difficult authenticity and reliability issues such as 'teaching the test' or 'to the test' and teacher bias.	Fewer authenticity issues.
10% moderated by NZQA	10% moderated by NZQA

9.9.1 Achievement Standard 90190: "Aspects of Geology": What are the key criteria?

The assessment material for AS 90190 (the key and only geology achievement standard for Science at Year 11, NCEA Level 1 and derived from curriculum Level 6), involves development of descriptive, explanatory and discursive questions. It is worth three credits and is set and supervised externally. The criteria for assessment include: (Note postscript discussion of Geology content changes).

a) Types of rocks (all of the following):
b) Igneous: Rhyolite, pumice, granite. Andesite and Diorite. Basalt, Scoria, Gabbro and Obsidian.
c) Metamorphic: Slate, Schist, Gneiss and Marble.
d) Sedimentary: Conglomerate, Sandstone, Siltstone, Mudstone, Limestone and Coal.
e) Formation (origins) of rocks.
f) Design and use of classification keys for identifying rocks (**not obligatory**).
g) Rock cycle and links to environment and geological events.
h) Relative age relationships from undeformed stratigraphic columns with links to explanatory sequential geological events.

9.9.2 Unit Standard 6358: "Describe the formation of major rock types and describe the rock cycle": What are the key criteria?

This standard represents an 'equivalent' unit standard for geology assessment that counts towards a national certificate qualification in Science at Year 11, NCEA Level 1 and derived from national science curriculum Level 6. This curriculum was established in 1993. This standard is worth three credits, moderated by NZQA and is set and supervised internally by the classroom teacher or Science department.

The criteria for assessment include:

a) Description of igneous rocks in terms of source material cooling and location. Rock types include knowing one from granite and gabbro and two from rhyolite, basalt, andesite, scoria, pumice, obsidian and ignimbrite.

b) Description of metamorphic rocks in terms of source material, heat and pressure and sequence of events. Rock types include knowing two from slate, schist, marble and gneiss.
c) Description of sedimentary rocks in terms of source material and environment of deposition. Rock types include knowing two from conglomerate, sandstone, siltstone and limestone.
d) Description of the rock cycle with links to geological processes.

9.9.3 What are the Differences?

There is a narrower range (sufficiency) requirement for unit standards implying unequal expectations. For example, knowledge of all rock types is required for AS 90190 whereas seven out of 17 years are required for US 6358. Although not obligatory for AS 90190, design and use of classification keys for identification of rock types may be examined and still needs to be taught. Identification keys are not included in US 6358 criteria but are included as part of one element in US 6357 but confined to identifying rock classes (Igneous, Metamorphic & Sedimentary) and not rock types. The key difference is that AS 90190 includes assessment of the fundamental concept of relative geological time through the use of fossils, the laws of superposition and possible explanatory geological histories. US 6358 does not include these basic geological concepts and so the majority of students leave school knowing nothing about the greatest contribution that geology has given to science.

9.10 Geology, Evolution and the 2007- 2010 Science Curriculum Review

The draft curriculum review document was released for public and professional discussion in August 2006 with the final version available in November 2007. The boxes below extract the relevant proposed curriculum achievement aims for biological evolution and geological time. The challenge for New Zealand teachers is to build the expertise for teaching biological evolutionary concepts and accurate concepts of geological time across all Levels with the development of valid, and equitable national assessment tasks in a criterion referenced environment. Fossils and the fossil record are not specifically mentioned in any part of the revised Science curriculum. Furthermore, in the September final draft of the national Science curriculum, there is an emphasis on internal and external geological processes but this is divorced from what geology contributes to our understanding of the world: ‘deep geological time’.

Science Achievement Aims for Living World Strand – Biological Evolution

“Students will understand the processes that drive change in groups of living things over long periods of time and be able to discuss the implications of these changes”.

Science Achievement Aims for Planet Earth and Beyond Strand
- Earth Systems

“Students will investigate and understand the spheres of the Earth System – geosphere (rocks and soil), hydrosphere (water), atmosphere (air) and biosphere (life)”

Science Achievement Aims for Planet Earth and Beyond Strand
- Interacting Earth System

“Students will investigate and understand that the hydrosphere atmosphere, geosphere and biosphere are interconnected by a complex web of processes”.

Evolution Objectives at Level 6 (age 15/16 or year 11) Living World Strand

- “Explore patterns in the inheritance of genetically controlled characteristics. Explain the importance of variation within a changing environment.”

Life, ecology, and evolution Objectives at Level 8 Living World Strand (Age 17/18 or year 13 - the final year of secondary in New Zealand)

- “Understand the relationship between organisms and their environment” and
- “Explore the evolutionary processes that have resulted in the diversity of life on Earth and appreciate the place and impact of humans within these processes”.

Figure 9.11. Science Achievement Aims for The Living World strand.

It should be noted that these achievement objectives thematically thread through the science curriculum from Year 1 to Year 13 (ages 5 to 18 years) so students are exposed to thinking in evolutionary terms in biology from the beginning of their school education years. This introduction of evolution as a guiding theme across all Levels is new to the New Zealand science curriculum and has not been without disagreement. This disagreement came largely from ‘special character’ Christian-based schools (w.w.w.minedu.govt.nz/web/downloadable/dl11958_v1 /supplementarydraftcurriculumreport-25022007-lift.doc) who possibly see this as a threat to fundamental beliefs about the world and a perceived tension between Science, religion and materialism. Anti biological evolution ideas based on religious thought is of course pseudoscience and has no place in a Science curriculum (Allchin, 2004; Eve, 2007; Lederman, 2008). In a recent New Zealand Geological Society newsletter article, Campbell (2008) suggests that the Ministry of Education has a ‘laissez faire’ attitude towards the teaching of evolution and schools are seen as free to decide their own approach to its teaching. Misconceptions about the nature of science and scientific theories are not, it seems, confined to the US. Furthermore, Campbell implies that anecdotal evidence suggests that like those in the US (Berkman, 2008), some New Zealand teachers of biology hold creationist ideas themselves or are wary of community and even colleague pressure when teaching evolution, and therefore are scientifically compromised. This is an area of important future research.

King, (in press.), has developed a scheme in which to analyse the solid earth geological components (geosphere) of Earth Systems Science from a variety of national curricula. King analyses curricula from the USA, Israel, Japan, Scotland, South Africa and Taiwan. This scheme was used to analyse the relationship between Earth System Science and solid Earth geology in the New Zealand Science curriculum and is presented in Tables 9.4 and 9.5.

Table. 9.4. Framework for the New Zealand Earth Science strand of the national Science curriculum.

8 Elements Earth Science Analysis Scheme (After King, 2007, pers. com)	**Age Group**	**Earth Science Achievement Objectives from the New Zealand national Science and Biology curricula as related to the "Framework for Earth Systems Education" (After Mayer, 1997)**
Geological Time	**5-18y**	**None.**
Evolution of Life	**5-18**	**None.**
Earth Materials	13-14	Investigate the composition, structure and features of the hydrosphere and atmosphere.
Earth Energy	13-14	Investigate how heat from the Sun, the Earth and human activities is distributed around the Earth by the hydrosphere and the atmosphere.
Earth as a System	11-12	Investigate the water cycle and the effect on climate, landforms and life.
	13-14	Investigate the external and internal processes that shape and change the surface features of NZ.
	15-16	Develop an understanding of how the four spheres interact to cycle Carbon.
	15-16	Develop an in-depth understanding of the interrelationships between human activities and the atmosphere, geosphere, hydrosphere and biosphere over time
Natural Hazards	16-17	Develop an understanding of the causes of natural hazards and their interactions with human activity on Earth.
Resources and environment	11-12	Develop an understanding that water, air, rocks and soil**,** and life make up our planet and appreciate that these are also the Earth's resources.
Investigating the Earth	**5-18**	**None.**

Table 9.5. Framework for the New Zealand Living World strand of the National Science curriculum for evolution.

Key Evolution Element of the Earth Science Analysis Scheme (After King, 2007, pers. com)	**Age Group**	**Earth Science Achievement Objectives from the New Zealand national Biology curricula as related to the "Framework for Earth Systems Education" (After Mayer, 1997)**
Evolution of Life	5-6y	Explain how we know that some living things from the past are now extinct.
	7-8	Explore how the groups of living things we have in the world have changed over long periods of time. Some living things in NZ are quite different from other living things in other areas of the world.
	9-12	Describe the basic processes by which genetic information is passed from one generation to the next.
	13-14	Explain the importance of variation within a changing environment.
	15-16	Explain how the interaction between ecological factors and natural selection leads to genetic changes within populations.
	17-18	Explore the evolutionary processes that have resulted in the diversity of life on Earth and appreciate the place and impact of humans within these processes.

The eight element scheme of King is an attempt to identify the key Earth Science concepts that are pertinent to Earth Science curricula. For the New Zealand Earth Science component of the national Science curriculum, it is clear that the exclusion of **geological time**, **evolution (in a geological context),** and **investigation** is a significant dilution of the values an earth science literacy that may provide for future citizens (AGI, 2004). A key exclusion from the Living World strand (Table 9.5) appears to be the links between evolution and geological time. Nothing in biological evolution makes sense without reference to geological time (Baker, 2000). And scientific literacy is incomplete without it (Orion, 2007).

In terms of the well known Earth Systems (ESS) understandings (Table 9.6 Appendix 3), and although a systems approach has been invoked, the New Zealand science curriculum does not satisfy much of the understandings that ESS is founded on, such as understandings 1 (The uniqueness of planet Earth), 5 (Age and evolution of the planet) and 7 (Careers).. Understanding 6 (Place of Earth in the universe) is catered for in the astronomy section of the *Planet Earth and Beyond* strand of the Science curriculum.

Geological time is a crucial conceptual element of scientific literacy and one of the 'gifts' of geological science to our modern scientific understanding of our planet's history (See Chapter 7). Orion (2007) and King (pers. com) point out that geological time is an essential concept for inclusion in any Earth System course and its exclusion in the New Zealand Science curriculum deprives students from making scientific connections about how the planet functions and the bio/geological processes involved. Other essential learning concepts expressed by Orion include: development of 3-D spatial visualisation skills, development of deep time and space dimensions and development of cyclic and systems thinking in units of teaching and learning.

9.11 Assessing Geoscience in the New Zealand Science Curriculum: What About Geological Science?

The New Zealand Science curriculum has undergone many revisions since 2005. The curriculum strand title "Planet Earth and Beyond" has also 'morphed' into "Planetary Science" leaving the status of geological science somewhat in confusion. The current final draft of November 2008 is open for general comment in preparation for implementation (but not without some criticism from the Secondary School Principal's Association and others, regarding a perceived short and difficult timeline and pedagogical issues surrounding subject integration of key competencies such as thinking skills, subject language and self management), in 2010. Alignment of external assessment tasks with standard achievement objectives is currently underway and unit standard alignment is still to be reviewed for implementation in 2010 (http://www.minedu.govt.nz/~/media/MinEdu/Files/TheMinistry/AssessmentPositionPaperSep2010.pdf.) The issue of operating, nationally, a dual, competency-based unit standard and criterion-based achievement standard system remains an issue. 'Teaching' the 'Nature of Science' is reflected in the internal assessment of 'pattern seeking' and 'fair testing' investigations, and the researching of secondary information. Integrated with this are the social 'key competencies' of 'managing self' and ‘relating to others’. If a school selects five external assessments then this is to be completed in two examination times.

Table 9.7 summarises the changes in externally assessed geological science objectives and contexts from the 2004 - 2010 achievement standard to that proposed for 2011. Time will tell what content will end up in examination in 2011, and the mix of assessment styles.

Table 9.7. Levels 1 - 3 NCEA external examinations for geological science (age 15/16 years).

Current AS 90190 (2002 -2010). “Aspects of Geology “. (3 credits). Note that assessment of minerals was removed in 2004.	**Proposed Standard AS 1.3** **(Nov. 2008 and implemented 2011)** *“Investigate the external and internal processes that shape and change the surface features of New Zealand”* *4 credits.*
Formation of selected igneous, metamorphic and sedimentary rocks	Indo-Australian and Pacific tectonic plate movement along the Alpine Fault
The rock cycle as linked to geological events and environments	Types of volcanoes and plate boundary
Relative stratigraphic age relationships	Earthquakes and plate movement
Sequential geological histories	Weathering. Erosion by wind, ice, earthquakes. Landslips and sediment deposition.
	Simple rock cycle

Level Two NCEA External Exams for Geological Science (Age 16/17 years)

Current AS 90762 (2004 -2010) “Describe NZ’s Geological History” (3 credits)	**Proposed Standard 2.5 (Nov. 2008)** *“Develop an understanding of the causes of natural hazards”. (4 credits)*
Geological *processes* include: Plate tectonic subduction and spreading, mountain building and peneplanation. Geological *events* include: Pre Gondwanaland events; breakup of Gondwanaland; rock types associated with major orogenies; tertiary peneplanation; Ice Ages.	Causes of earthquakes, volcanoes, landslides, tsunamis, storms, meteorite hits, tectonic activity, extreme weather, storm surges.
	Proposed Standard 2.6 (Nov. 2008) *“Develop an understanding of the interaction of natural hazards with human activity”. (4 Credits).* Effect and consequences of AS 2.5.

Level Three NCEA External Exams for Geological Science (Age 17/18)

Current AS 90731 (2004 – 2010)	**Proposed standard 3.5 (Nov. 2008)**
"Describe geological processes affecting NZ". (2 Credits) "1. Plate tectonics: simple plate tectonic theory including subduction zones, deep sea trenches, mid-oceanic ridges, and transform faults. 2. Seismic activity: the cause, nature, measurement, and distribution of earthquakes, knowledge of P and S waves. This will include the description, detection, measurement and use of P and S waves in locating earthquake epicentres and determining the nature of the Earth's internal structure. 3. Measurement of earthquakes is limited to the Richter and Modified Mercalli scales. 4. Volcanic activity: types and locations of dormant and active volcanoes and volcanic activity areas, associated phenomena such as geothermal activity, relationship between magma type and volcanic features".	*"Develop an understanding of the interrelationship between the geosphere, hydrosphere, atmosphere and biosphere over time". (4 credits)* Geosphere, Biosphere, Atmosphere and Hydrosphere – how these interrelate on a global scale. Note that the current Achievement Objective states: "Develop an in-depth understanding of the interrelationship **between human activities** and the geosphere, hydrosphere, atmosphere, and biosphere over time", whereas the proposed aligned standard above, does not specifically connect human activities with earth systems.

9.12 Discussion

The proposed standards at Level 1 indicate significant change from a standard requiring conceptual knowledge and understanding of the formation of rocks, geological environments, geological time and geological histories, to one dominated by physical geological processes as explanation for observable surface features. The key elements of geological science such as deep time and geological history have been removed not only from Level 1, but also do not reappear as examinable materials in any achievement standard. Emphasis appears to be on the consequences of plate tectonics such as types of volcano, boundaries and earthquakes, rather than on geological explanations of mechanisms. This is a significant reduction in enabling students to develop a concept of the Earth's global and local geological history and an understanding of the accumulated multi-disciplinary scientific evidence. Having a meaningful perception and conception of geological events enhances understanding of the universe and the interrelationships between different science disciplines. Furthermore, the deep time and perceptions of scales of time have an important impact on the conceptualisation of biological evolution.

As Libarkin et al. (2007) point out;

> *"Consideration of the role that deep time has to play in shaping our geologic conceptions should be an important point to consider when developing new curricula or pedagogies. Future studies could investigate ….. and evaluate the impact of time related curricula on students' Earth related conceptual models". (Libarkin, et al, 2007, p. 421).*

Although there is currently no specific supporting research evidence, possible reasons for this change in geoscience and geological science curricula include:

- Inadequate understanding by curriculum developers of what geological science actually is and why it is vital for making sense of all sciences. For example there were no geologists on the Science writing panels.
- Dominance of assessment for accountability and comparability rather than a curriculum for developing a scientific understanding of the planet and the universe. For example, this is supported in Hipkins (2010) on the evolution of the NCEA,

  > *"…positive cluster principals were curriculum innovators. They were likely to say their school had initiated curriculum and pedagogical changes aligned with the directions signalled in NZC, and to hold the view that a breadth of learning experiences and multiple learning pathways can legitimately contribute to an NCEA qualification" (p. 53).*

- Perception that students are cognitively unable to comprehend deep time and relative geologic events.
- Perception that students (and teachers) are bored and disinterested by learning about the formation of rocks, rock types and the rock cycle.
- Perception that geological science is of low status relative to other sciences. This perception is supported by assessment standards having a lower credit value and in the 2007 reforms, removal from external examination (http://nzcurriculum.tki.org.nz/e/community/ncea/science.php).
- Perception that earth systems science better satisfies a demand for showing how science is relevant to society and that this will enable better informed citizen decision making in the future.

The proposed standards (especially for Level 1) are strongly based on theory and leave little room for development of practical activities (except for aspects of weathering and erosion). Although these standards are in draft form, and that changes are to be expected, there is a clear change in the curriculum at Levels 2 and 3; from geological processes to socio/environmentalism. For example, the causes of natural hazards are developed into standard 2.6 where human activity interacts with natural hazards. In fact, geological phenomena are only seen as hazards if people are involved. Time will tell what the detailed unpacking of explanatory notes will dictate what teachers actually end up teaching the curriculum. Appendix 3 provides a detailed summary of where Geology qualifications come from in the current New Zealand curriculum.

9.13 What is Actually Assessed? – AS 90190 "Aspects of Geology"

Achievement standard AS 90190 is a key standard for the teaching and learning of the Earth Sciences as this is where most credits in geology are generated in the national qualifications framework in secondary school. It was first examined in 2002 and contained criteria on formation of rocks, geological history, relative dating and observable properties of minerals. Revision of standards at the end of 2004 saw the elimination of minerals from examinable material from AS 90190 so that students are now expected to have knowledge of types of rock, the formation of igneous, metamorphic and sedimentary rocks and an understanding of relative age relationships in simple (non overturned) stratigraphic columns. The analysis of the stratigraphic columns addresses the order in which geological events occur and their relationships to geological processes. Classification keys for rocks may also be assessed but has only been asked in the 2002 examination for AS 90190. The full description of the AS 90190 criteria is available on www.nzqa.govt.nz.

Based on the arguably valid Bloom's taxonomy, students are assessed according to the quality of answers by:

a) *Description* - *requires* the student to be able to recognise, name, draw, give characteristics of or an account of.
b) *Explanation* - requires the student to provide a reason as to how or why something (concept or observation) occurs.

c) *Discussion* - requires the student to show understanding by linking scientific ideas. It may involve students in justifying, relating, evaluating, comparing and contrasting, analysing.

Questions are also constructed so as to enable students to achieve the standards criteria in a balanced sufficiency distribution of questions requiring description, explanation and discussion. Many questions are 'scaffolded' so that students can gain credit for a discussion answer that is explanatory rather than discursive and descriptive rather than explanatory. Discussion requires high level skills at linking ideas, and only skilled students are able to achieve this level of understanding. Results reflect a students' overall level of achievement from a pre-determined sufficiency statement. The sufficiency statement specific to each standard is carefully adjusted during marking time to ensure some control over unexpected and aberrant interpretations of questions and to reduce result variations. This may at times be a contentious issue and is often misinterpreted as 'scaling' rather than managed and controlled adjustment.

Typical examples of descriptive, explanatory and discussion questions from the November 2006 exams for Geology AS 90190 are shown below.

AS 90190 *"Aspects of Geology"* 2006 Exam Questions Examples.

Descriptive: "Describe what is meant by the term 'stratigraphic column".

Explanatory: "Granite is light in colour and gabbro is dark in colour. Explain why these two rocks differ in colour".

Discussion: "Discuss the *differences* in the formation of granite and basalt."

Teachers have always relied on examination questions as powerful indicators of 'syllabus' and standard criteria interpretations so that teachers can better prepare their students for examination. However, poorly explained and narrow criteria of standard 90190 severely limit what can actually be asked and in turn limit the 'shelf life' of the assessment standards. Over time, it eventually becomes easier for teachers to 'second guess' the questions because there is a limit as to what can actually be asked. Questions cannot be asked outside these criteria. Many individual questions are 'scaffolded' to enable students to demonstrate their level of understanding.

Assessment schedules are available for download and discussion from www.nzqa.govt.nz. Considerable debate has ensued over the actual and potential manipulation of accepted judgement statements for students (and therefore school) performance in comparison to Profiles of Expected performance (PEP). The following is taken from the NZQA website (nzqa.govt.nz/nqfdocs/ncea-resource/pep/2006/90190-pep-06.pdf) and details the performance expectations for the 2006 external exam for AS 90190. Use of PEP's is controversial.

> *"Profiles of Expected Performance (PEP's) are established for each externally assessed achievement standard using a combination of historical data and the informed professional judgements of examiners, markers and NZQA staff. Each PEP provides NZQA and the leaders of marking panels with a measure against which to gauge the real-time progress of marking. Where outcomes begin to deviate from the PEP's, NZQA and panel leaders consider whether: An amendment to the marking schedule will correct the discrepancy· There is an explicable and defensible reason for any change in performance· Any further action is required or justified."* (p.1)

For the AS 90190 external examination for 2006 it was expected that 44 -50% of candidates would fail (N = Not achieved), 33–38% would achieve (A), 11–17% would achieve with merit (M) and 2-5% would achieve with excellence (E). Compare this with Figure 8.22 (1 is AS 90190), where the averaged results from 2002 to 2005 were 49.5% N, 39.3% A, 9.4% M and 1.9% E. These results indicate that expectations were achieved for failure and achievement but not for merit and excellence, which were below expectations. Is the historical 50% pass/fail mindset from pre 2002 scaled and norm referenced external exams alive and well in an SBA environment? The derivation, use, management and relationship to actual student performance remain a critical area debate for SBA validity, reliability and authenticity of student results.

Figure 9.18 in Appendix 3 shows the quality of performance for selected Earth Science achievement standards from 2002 to 2005. The descriptors for selected standards are shown in Table 9.8. Over all standards in Figure 9.22, the average 'pass rate' is 50% thus begging the question of why is this not significantly different to that achieved in the previous norm referenced system of 'scaled' percentage marks , and does the achievement standard criteria really differentiate those students with higher Level thinking skills?

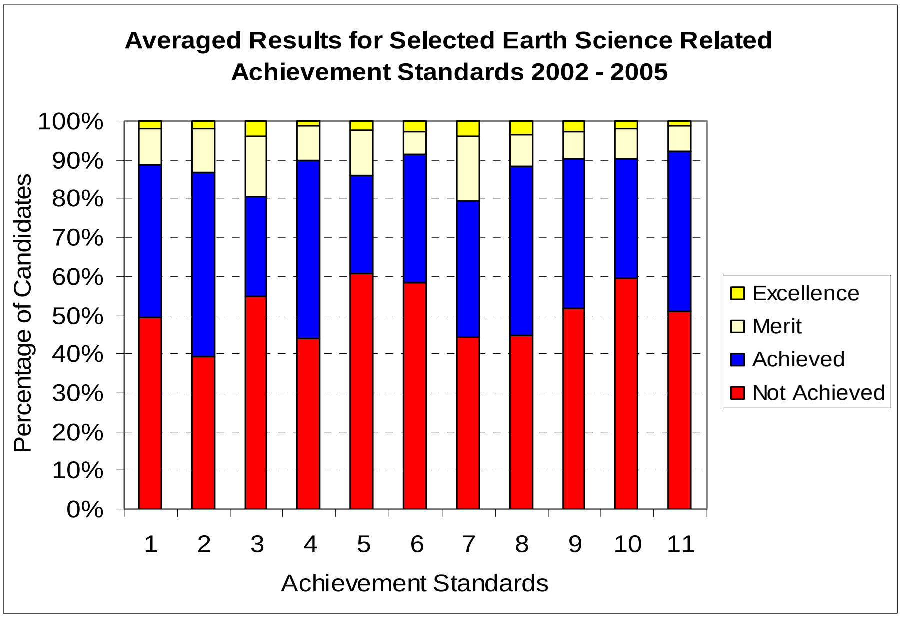


Figure 9.22: Achievement in selected Earth Science achievement standards.

Table 9.8. Achievement standard descriptors for Figure 9.22.

	AS No.	Level	Domain	Title	
1	**90190**	**1**	**Science**	**Aspects of Geology**	Planet Earth and Beyond
2	**90192**	**1**	**Science**	**Aspects of Astronomy**	
3	90331	2	Geography	Natural landscapes	
4	90719	3	Science	Human evolution	
5	90717	3	Biology	Processes and patterns of evolution	
6	90316	2	Science	NZ geological history and processes and the nature and life cycle of stars	
7	90731	3	Science	Geological processes affecting NZ	
8	90772	2	Science	Evolution of NZ plants and animals	
9	90764	2	Science	Life cycle of stars	
10	90767	2	Science	NZ geological history	
11	90314	2	Science	NZ endemic life	

9.14 Results Gaining Credit in Geoscience Standards: A Discussion

Figure 9.23 shows candidate achievement comparisons for geoscience unit standards and other NCEA Science standards for 2006. Level 1constitutes the main area of formalised contribution to teaching and learning about planet Earth as relatively few students gain credits after this. This is mainly a result of so few secondary schools offering Science at Year 12 and 13 (Figure 9.28, Appendix 3,). Indeed in 2007, there were only 177 (41%) schools offering Geology at level 1, 50 schools at Level 2 (11%) and 26 schools at Level 3 (6%). Achievement is defined here as the number of results in that year that gain students credit and not 'quality' of understanding as in merit or excellence. There are 2.5 times as many candidates gaining credits in physics as there are in geology, 2.4 times as many in chemistry and 1.6 times as many in biology. Geological science is in serious decline as a subject of learning. In summary, despite *"Planet Earth and Beyond"* being established and formalised into the 1994 New Zealand Science curriculum reforms currently, very few schools, and therefore students, have an opportunity to learn about geological science. What is taught is Level 1 (with seriously declining numbers) AS 90910 *"Aspects of Geology"* and NZASE unit standards with a scattering of other unit standards in Geology at Levels 2 and 3. As the future of NZASE unit standards is in doubt (see postscript) even fewer students will have an opportunity to learn about the geology of our planet.

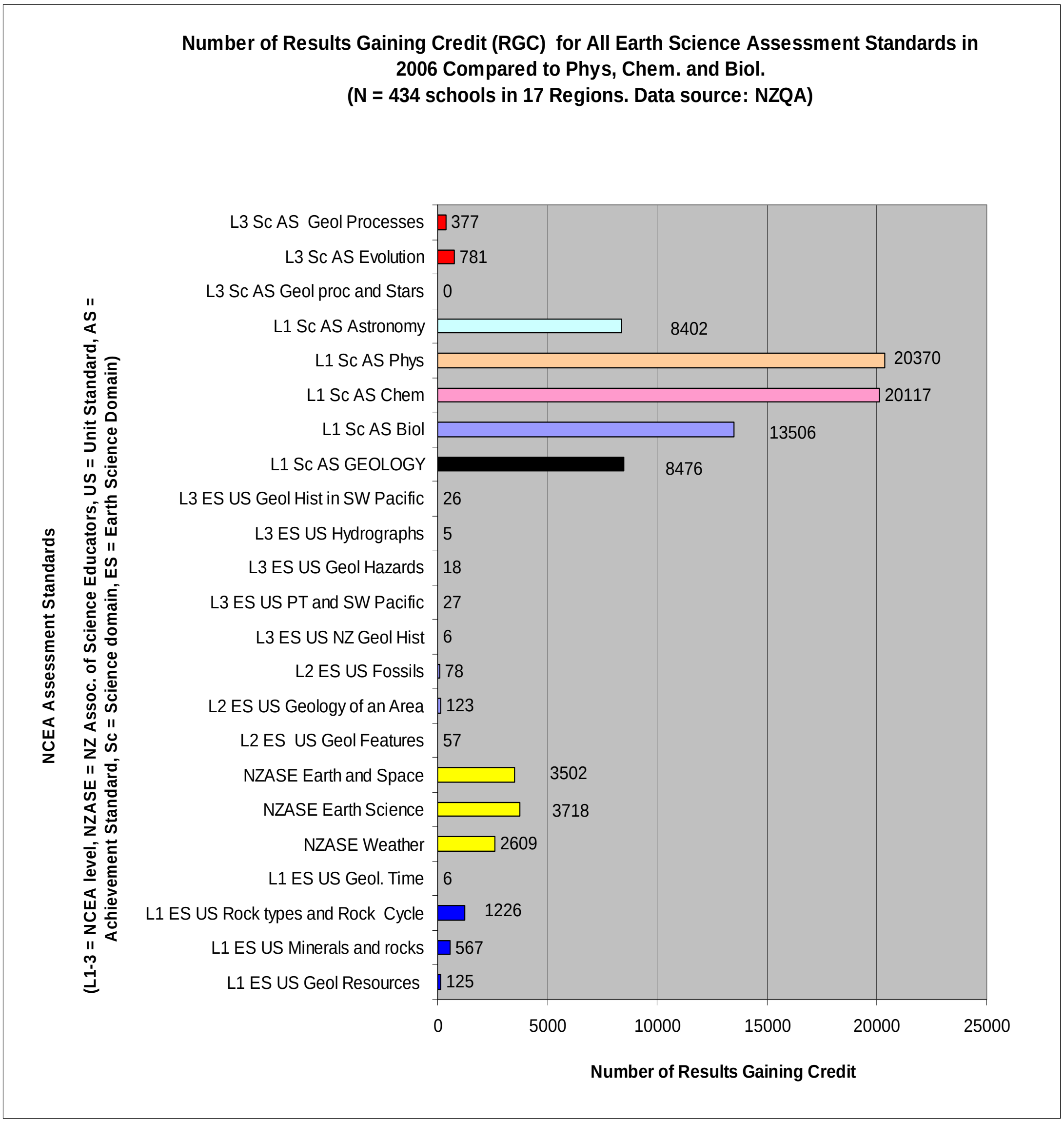
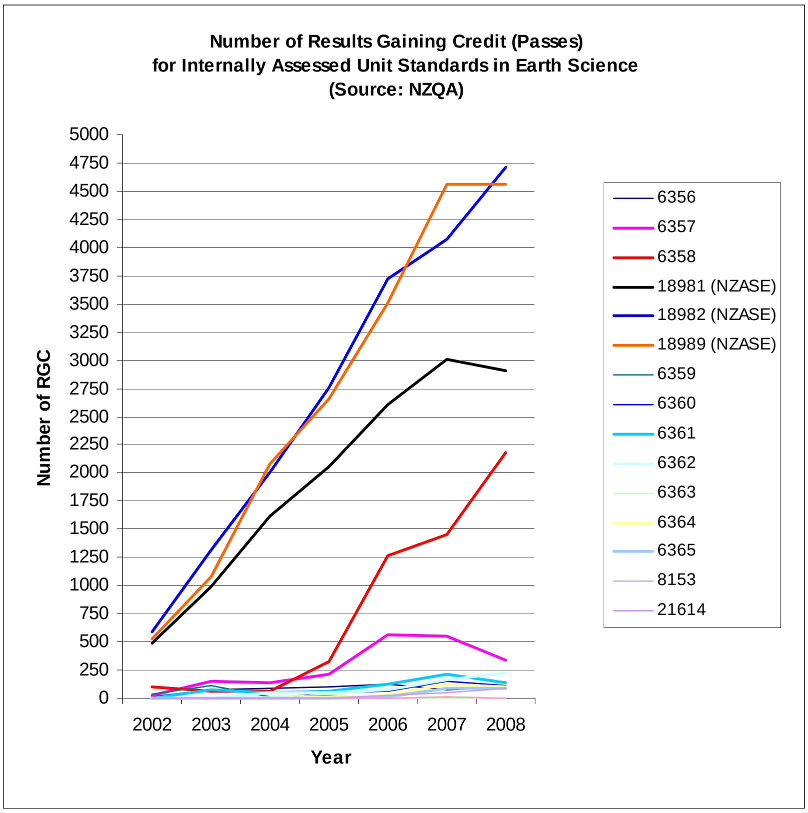


Figure 9. 23. Results comparisons for all Earth Science Assessment Standards 2006.



Key to Earth Science Unit Standard Numbers

L1 US 6356	Report on a geological resource in NZ
L1 US 6357	Identify common minerals and rocks
L1 US 6358	Describe the formation of major rock types and describe the rock cycle
L1 NZASE US18981	Demonstrate basic knowledge of weather
L1 NZASE US18982	Demonstrate knowledge of Earth Science
L1 NZASE US18989	Demonstrate knowledge of Earth and Space
L1 US 6359	Demonstrate knowledge of the measurement of geological time
L2 US 6360	Identify geological features from recorded visual information
L2 US 6361	Investigate and report on the geology in an area
L2 US 6362	Demonstrate an understanding of fossils
L3 US 6363	Demonstrate knowledge of the geological history of NZ
L3 US 6364	Use plate tectonics to explain distribution of major NZ and SW Pacific geological features
L3 US 6365	Demonstrate knowledge of natural hazards
L3 US 8153	Explain factors affecting water resources and its management, plot and interpret hydrographs
L3 US 21614	Describe the geological history of an area in the SW Pacific

Note: L1 is Level 1 of NCEA and set for Year 11 (15/16 year olds).
NZASE is set for lower ability Year 11 students at curriculum Levels 3, 4 and 5. NCEA Level 1 Unit Standards (US) is set for curriculum Level 6 (Ministry of Education, 2007).

Figure 9.24. Results gaining credits for Earth Science Unit standards.

Figure 9.24 tells an important story and tracks the changing pattern of where students gain their qualifications in earth science and what many schools are offering their students, for an earth science education. Unit standards are totally internally managed. The NZASE standards have undergone some revision in 2008 but the assessment tasks have remained essentially the same each year. Although there is a rigorous external moderation system, teachers are able to ‘teach to the test’, and even ‘teach the test’ (see Table 9.3). NZASE assessment tasks are derived from the lower curriculum Levels 3, 4 and 5 rather than curriculum Level 6 for all other NCEA Level 1 qualifications. They are designed for lower achieving 15 year old students and significant debate is yet to be had on the future retention of these standards as counting towards the national qualification of NCEA Level 1. Based on a premise of non duplication of standards, recent (September 2009) curriculum revisions indicate that unit standards will be removed.

Since the introduction of standards based and criterion referenced assessment in 2002 there has been a rapid increase in the number of students gaining their Earth Science credits from unit standards in particular, from the NZASE option. The 2008 results indicate an interesting decline in two of the three NZASE earth science unit standards but not geological science. 2009 results will not be available until May 2010. There is a continuing increase in the NZASE standard 18982: Demonstrate knowledge of Earth Science and the Level 6 curriculum standard 6358: formation of rocks and the rock cycle. A decline in the number of students gaining credits in 6357: identifying rocks and minerals is noted, and likely to continue to decline. It is also likely that as the number of students gaining credits in the curriculum Level 6 externally assessed achievement standard AS 90190 (Aspects of Geology) decreases, the number of students gaining credit in the internally assessed US 6358, has increased. Does this reflect schools competitive desires to have more students ‘passing’ by offering a perceived easier pathway to gaining credits? And, how much subject choice do students really get? Either way, the number of students gaining credits in the earth sciences is in decline and places in jeopardy the survival of this subject in the NZ national curriculum. In concert with 2009 curriculum reforms where geological and earth science will no longer be externally assessed, survival is in even more question and doubt. Senior Level earth science standards have always been low in number and remain static at less than 250 students per standard.

9.15 Where Do Evolution Related Qualification Credits Come From?

Although relatively few students gain credits in Biology standards (www.nzqa.govt.nz/qualifications/ssq/statistics/nqf-stats.) at NCEA Level 1 compared to Biology in Science standards, (maximum of 6572 for AS 90163 *“Describe transfer of genetic information”* compared to 20,000 in Biology in Science for 2006), there are no evolution related standards for assessment. Consequently, students currently are formally taught very little about scientific explanations and mechanisms for the evolution of life until senior secondary school. Figure 9.25 and standard descriptors (Table 9.9) show the standards which contribute to credits in the assessment of biological evolution. It is notable that unlike Geology standards, credits are gained essentially through achievement standards rather than unit standards and reflect traditional ‘pre 2004 SBA’ teaching. This is shown by the fact that AS 90459, AS 90717 and AS 90719 were already part of what was taught in Biology before SBA. The lower number of results gaining credit for AS 90772 is a standard for assessing the evolution of New Zealand’s plants and animals within the Science domain (Level 2) and not Biology, again reflecting the fact that few schools offer Science at NCEA Levels 2 and 3.

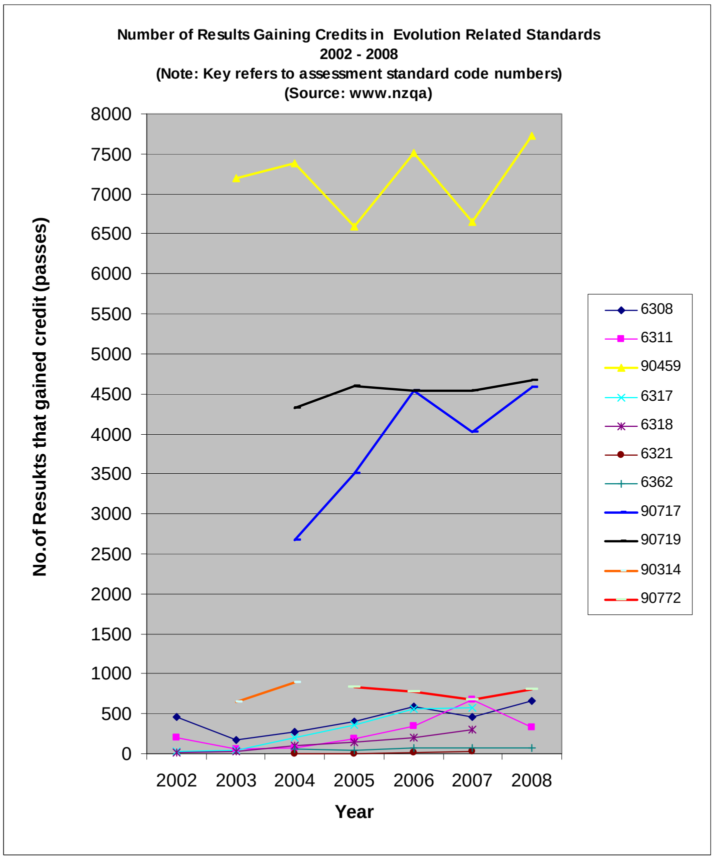


Figure 9.25. New Zealand evolution related standards and credits gained.

Note: Results gaining credit do not indicate total candidate numbers per subject. NZQA did not hold the number of entries for unit and internally assessed achievement standards prior to 2008; as from 2008 schools/tertiary providers will have to send to NZQA the number of students who attempted standards but did not gain an achieve or higher. Unit standards do not carry Levels of achievement they are competency based only. Schools and tertiary providers only send in results (i.e. Achieve, Merit, Excellence -A, M, E) and not the number of students who attempted standards but did not achieve them. As from 2010 unit standards will be phased out.

Table 9.9 Descriptors for Evolution related national assessment standards.

	Assessment Standard	Descriptions (red indicates main credit sources)
1	US L2 Biology 6308 (Unit standard, NCEA Level 2 Biology domain, standard number)	Explain how genetic change occurs within populations.
2	US L2 Biology 6311	Reasons for the special characteristics of New Zealand's flora and fauna.
3	**AS L2 Biology 90459**	**Describe genetic variation and change (about 25% is evolution related).**
4	US L3 Biology 6317	Explain the process of speciation
5	US L3 Biology 6318	Interpret scientific information for human evolution
6	US L3 Biology 6321	Scientific views of human biological evolution
7	**US L2 Science 6362**	**Demonstrate understanding of fossils**
8	**AS L3 Biology 90717**	**Processes and patterns of evolution**
9	**AS L3 Biology 90719**	**Describe trends in human evolution**
10	US L4 Biology 8105	Explain the principles of evolution and biogeography
11	AS L2 Science 90314	Describe aspects of NZ's endemic life
12	**AS L2 Science 90772**	**Describe the factors and processes involved in the evolution of New Zealand plants and animals (replaced AS 90314 in 2005)**

Achievement results for evolution related standards also reflect the well established fact that as socio economic deprivation declines so do 'pass' rates or achievement (Figure 9.22) in standards assessments. Although decile 6 schools only contributed 50 candidates (out of a total of 1493 in 2005) for AS 90772 it is unclear why their success rate for this standard is so high. Low decile schools also contribute fewer candidates. Private schools do not have decile ratings and therefore do not receive government funding assistance. These schools have fee paying students and therefore are more likely to have high socio-economic status with high expectations and values for academic success. Pass rates may also reflect to some extent, what students choose to be the standard(s) that are most likely to provide them with success. For example, students may be entered in all biology assessments for a particular NCEA Level but on the day of examination choose to sit or answer only those questions and papers that they perceive to be important. This issue of completing all papers in a single three hour examination has been partially addressed by enabling passes with endorsements of 'grade' Level to be placed on the record of learning. This is an attempt to motivate students into thinking beyond 'just a pass'.

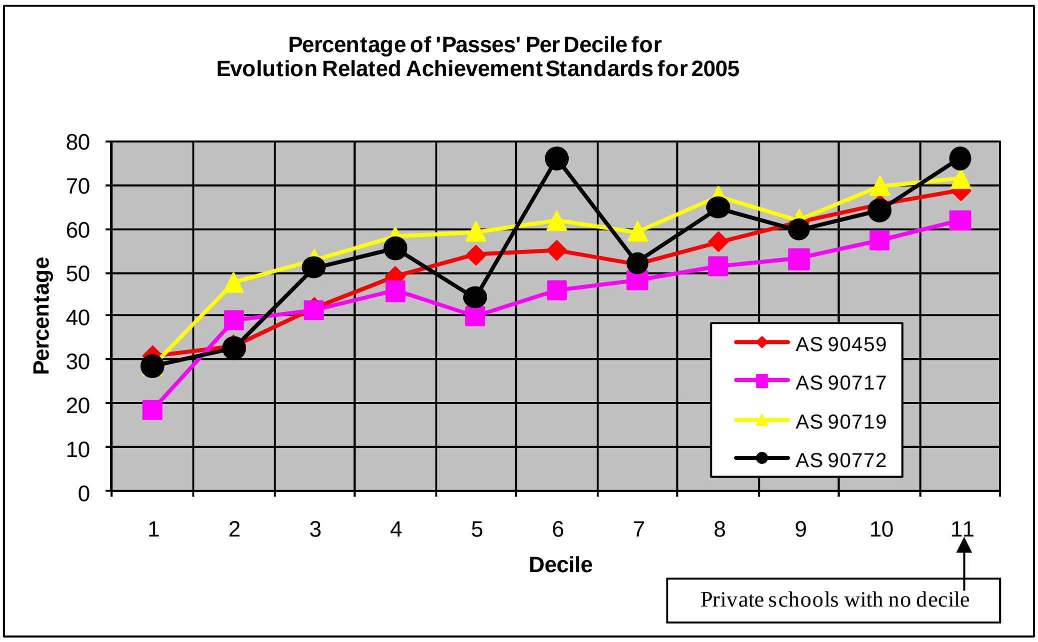


Figure 9.26. Deciles and Percentage "Pass rates" for evolution related standards.

Although there are twelve assessment standards that are available for the teaching and learning of biological evolution principles, Figure 9.26 shows that AS 90459, AS 90717 and AS90719 are the standards that teachers teach. At NCEA Level 2 AS 90459 provide only a small percentage actually related to evolution ideas. There are far fewer candidates in AS 90772 because very few schools offer Science at Year 12. Although there is a similar trend, the gap between AS 90717 and AS 90719 is perhaps best explained by fewer numbers of students entering AS 90717 rather than quality of student. Perhaps "Human evolution" has more appeal than "processes and patterns"?

9.16 Chapter Summary

1. The Geology component of the *Planet Earth and Beyond* strand is an established part of the NZ national Science curriculum but with continuously and significantly declining numbers of candidates attempting and/or being taught by schools. This decline is a serious concern if an uneducated public (and politicians) are required to make informed conclusions and decisions on

climate change, evolution of life, environmentalism, Earth materials (rock, mineral and soil) and geological processes. Geology as a discipline of learning in secondary school in New Zealand continues to struggle for survival and is in effect dead beyond Year 11 and dying at Year 11. In one of the world's most tectonically active regions and dependence on soils for an agriculturally-based economy, understanding of geological processes and the impact of human intervention on geological/environmental issues is vital for future economic sustainability.

2. Schools appear to be choosing to offer less demanding assessment standards such as NZASE and unit standards at the expense of achievement standards. These enable students to express higher orders of thinking for meeting the perceived needs of teaching and learning for the geological sciences whereas unit standards and NZASE unit standards do not. Achievement standards such as AS 90190 also do not assess the same conceptual content as the equivalent unit standards and are externally assessed.

3. Data suggests that schools have not fully embraced the teaching and learning of geological science as part of the 'new' reformed 1994 national Science curriculum and continue to teach in a slightly modified form what they taught prior to its introduction. Curriculum conceptual traditions die hard. The Level of geological literacy in the general population (and within the teaching profession) is very low.

4. Assessment (and teaching) of Geology and evolution has always been and continues to be, minimally represented in the national Science curriculum and is actually studied by relatively few pupils compared to other traditional sciences. Fossils and paleontology continue to be minimalised in the New Zealand science and biology curricula.

5. The national Science curriculum is currently nearing the end of its review after 13 years of implementation. The draft was released for comment in August 2006 with continued recognition of the importance of evolution and geology at all Levels of Science. Assessment standards are in review for alignment with a final science curriculum statement. The completed curriculum and achievement standards-based assessments are due for implementation in 2010-2013. This will change the geological concepts

taught and assessed and increase the demands for improved and adequate pedagogic resourcing, training and funding (See postscript for current status).

6. High stakes assessment remains the crucial educational driving force and political ingredient in the teaching and learning continuum. Decisions on issues of funding, resourcing and teacher training for implementation of a reviewed curriculum (after 2010) are yet to be addressed.

7 Addressing issues for improvement of educational achievement and candidate numbers for the geological sciences in low decile regions and schools is a challenge. Data for the teaching and learning of geology in schools suggests that increasing funding alone (via government Targeted Funding for Educational Achievement: TFEA) to low decile schools does not appear to be effective in raising achievement Levels in this subject area.

8. The Nature of Science within the curriculum is seen as an overarching strand and aspects are integrated within all standards. Although this is beneficial to enhancing an understanding of biological evolution, geological time content is removed from the Planet Earth strand. This retards a better understanding of science in general and biological evolution in particular.

9. Analysis of data can never keep up with the latest set of results but this analysis shows how geological science was reborn, grew and died in NZ.

9.17 Postscript

Late November 2009 developments from the NZ Ministry of Education and its operations arm NZQA, announced several curriculum reforms as related to national qualifications. These will impact on the content and assessment for geological science and geoscience. In essence, criterion referenced unit standards will disappear (Except industry training organisations) so that only internally and externally assessed achievement standards will be operational. NZASE unit standard assessment will also disappear or be modified and external examinations will be of three hours with a maximum of three papers. Geological science will not be externally examined at Level 1, therefore reinstating the traditional reductionist sciences of physics, chemistry and biology to pre 1994 subject status. Because unit standards will not be available, the lower achieving students will also not be able to study the earth science standards. In effect the growth of NZASE standards contributing to NCEA Level 1will no longer exist and the existence of Science as a partner to the traditional senior high school reductionist hierarchy of Physics, Chemistry and Biology are in jeopardy. However, NZASE standards are likely to remain for lower achieving students but not count towards NCEA Level. The final format and philosophy remains to be seen. Figure 8.27 shows the pass rates for externally assessed achievement standards.

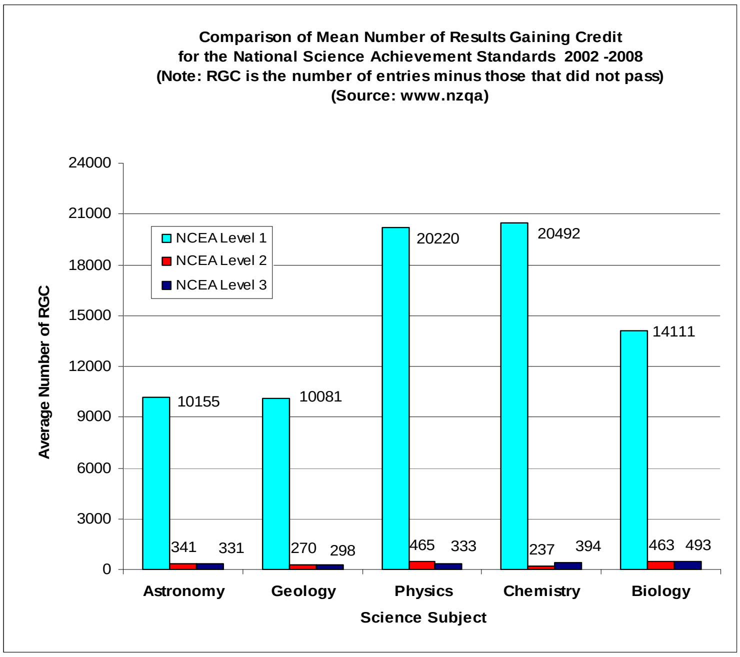


Figure 9.27. Mean number of results gaining credit 'passes' for Achievement Science national achievement standards 2002 -2008.

Bearing in mind that learning geological and/or geoscience in NZ can only be done (excluding minor aspects in geography) through the Science standards, Figure 9.23 details the average number of candidates over the last seven years who have entered for **achievement standards** and who have gained credits i.e. passed. Despite *Planet Earth and Beyond* being successfully introduced as an equal curriculum partner to the other sciences in 2002 for the introduction of NCEA into NZ culture, there is about a 96% loss of students from Year 11 (aged 15/16 at NCEA Level 1) to those who gain credits at Levels 2 and 3 NCEA Science. Schools simply did not take up the option of offering senior students a general science course but rather kept to the traditional reductionist hierarchy. Conceptual change is indeed difficult to sustainably produce. The challenge for future earth science teachers and others who value the unique contributions of geoscience and in particular, geological science, to science literacy and an informed understanding of how the earth works, is to find ways in which geological science and geoscience can be sustainably integrated into a Science curriculum. In effect, the current science reforms push the geosciences curriculum back to 1968 where there was no externally assessed geological science or geoscience. Yet NZ is a geologically volatile, dynamic and unique place!

Table 9.10 Geoscience curriculum changes.

NCEA Level 1 (students aged 15/16years): The first qualifications year.
What Changed in external national assessment of Geoscience?

1968 Curriculum	1994 Curriculum	2002 NCEA standards	2004 NCEA standards revised	2011 Curriculum
No geological or geoscience externally assessed.	Properties and uses of minerals and rocks. Formation of rock types. Geological history. A NZ natural resource.	Minerals, rock formation and the rock cycle. Geological history.	Rocks. Geological history	The carbon cycle. Plate tectonic processes and erosional forces involved in shaping surface features.

As can be seen from Table 9.10, there have been significant changes to geological and geoscience education curricula over the last 40 years. These changes range from recognition within the science curriculum of the importance and value of the geosciences in the 1994 curriculum relative to the existing physics, chemistry and biology, to its inclusion as a reduced credit standard in the initial NCEA standards. When revision of standards occurred in 2004, there was the removal of minerals from the assessable material (as derived from the Planet Earth and Beyond curriculum strand), and finally in the current revisions, rocks, geological history and minerals have been removed. These are replaced by assessable standards (internally only) on the carbon cycle (recognising the influence of Earth Systems) and the role of plate tectonics as an internal process and the erosion/deposition cycle as effecting surface features (See Chapter 3 for the 2010 achievement standards for understanding the formation of surface features and the cycling of Carbon). The key attributes of geological science such as ‘Deep Time’, structure, earth materials, earth history and the fossil record are removed from Level 1 (for 15/16 year olds).

In a proposed geological science content (NZQA draft matrix, Nov. 2009) for Year 12 Science, one paper will be externally assessed on "the causes of natural hazards" (4 credits) and another internally assessed paper looks at the "formation of rocks (formerly at Level 1) and its links to the geological history of an area" (4 credits). At Year 13 Science, one externally assessed paper looks at the "relationship between Earth system processes and the causes of global problems" (4 credits) and an internal paper looks at the "geological history of New Zealand" (4 credits). Of the approximately 55 schools currently offering senior Science, how many will do the external examinations in 5 years time? Indeed, whilst the number of schools offering NCEA Levels 2 and 3 Science remains low but static, the number of schools with students gaining credits in the Geology achievement standard at Level 1 is steadily declining with the number of schools offering lower curriculum level unit standards (NZASE) and internally assessed unit standards is increasing (see Appendix 3, Figure 9.28). The only access students will have for studying these key **geological concepts** will be at Years 12 and 13 Science Levels 2 and 3 NCEA. The record shows (See Chapter 12, p.330) that in 2008 only around 6000 students nationally entered for Level 2 Science and 25% of tuition time teaching geology. There were 1018 candidates (www.nzqa) entered for **Geology** at Level 2 in 2008, of which only 572 were successful. The statistics for Level 3 Science indicate 795 entered and 438 were successful. In short, there are very few successful candidates at senior school Level in NZ who can demonstrate an acceptable knowledge and understanding of geological science.

Will the next NZ Science curriculum 'reform' (AD 2035?) be up to the task of establishing and sustaining the vitality of geological science with adequate resourcing and teacher training? Who will do it, and is geological science and geoscience so boring and unimportant that students, teachers and future decision makers are uninspired? And what about the connections between geological science and biological science? Do the current biology reforms measure up and connect with geoscience? Current reforms are due for implementation beginning in 2011 with Level 1 NCEA.

Analysis of historical changes of GCSE Earth Science coverage in the national curriculum for the UK (King, 2007) shows a similar story to that of NZ where there is *“a bleak conclusion and an inconvenient truth”* (p. 5). Successive curriculum revisions have eroded the geological science content so that little remains. For New Zealand students, learning about how the Earth works, its history and connection with the evolution of life will be the pleasure of a tiny percentage of people.

The NZ geoscience (and geological sciences) curriculum experience so far, is echoed in King and Hughes (2007).

> *“……..it is a great shame that the Earth science content of science specifications,* [the UK curriculum] *which significantly improved in the 2000 specifications, has now taken a big step backwards. This seems particularly perverse at a time when understanding the Earth and its processes is becoming more and more scientifically important, and are likely to have a major impact on future generations”.(p.6).*

CHAPTER TEN

GEOLOGY AND EVOLUTION: GeoVAT SURVEY RESULTS

10.1 Introduction

As oxidation is to reduction so is the study of paleontology to an understanding of the evolution of life. Lyell, Darwin, and Russell were products of the western 'Age of Enlightenment' and their thinking formed the basis of geological science (as in the modern form of paleontology and paleoecology), and of the evolution of life on Earth. As Charles Lyell (1862) stated:

> *"Geology is the science which investigates the* ***successive changes*** *that have taken place* **in** *the* ***organic and inorganic kingdoms*** *of nature".*
> (Vol. 1. Ch.1.p.1.).

The connections between geological science and evolution are indeed historical and profound. Ever since fossils were recognised and accepted as the remains of once living organisms, the questions began: how, what, where, when and why but in a testable and accountable manner. From a teaching and learning perspective the challenge of conceptualising scientific views of the evolution of life has shaped curricula (or not) and the way people perceive the world's natural history. Investigating the history of life has been traditionally closely linked to the geological sciences, (particularly the study of sedimentary rock and biostratigraphy) rather than in Biology. Perhaps this is due to fossils having to be dug out of the ground: a task done by the geologist rather than the biologist and that Biology teachers tend to focus on structure, function and genetics rather than *paleo*ntology and *paleo*ecology. A significant conceptual challenge for teachers and curriculum developers is to bridge the content gap between the teaching and learning of extant life and the teaching and learning of extinct life and to integrate the paleobiological aspects of the geological sciences with those of the biological sciences. In Spain for example evolution was first introduced into the curriculum in 1901 and today makes up less than 7% of the Biology curriculum (Barbera, 1999). The fact that the teaching of evolution in Spain was entirely absent for forty years indicates the power of politics, religion and contemporary social issues on the construction of school curricula and in particular, societal values about biological evolution. Needless to say, political and religious issues of teaching biological evolution in the USA are extensively discussed.

Based on textbook analyses using word counts, other countries such as the People's Republic of China (PRC), USSR and the USA (Swarts, Anderson & Swetz, 1994) indicate that the teaching of evolution forms a relatively small portion of Biology curricula. Swarts, et al. (1994) also show that the former PRC textbook coverage of evolution is considerably less than the USA coverage but that the former USSR coverage is comparable and slightly more than the top USA textbook coverage. In a study of Turkish pre-service Biology students' acceptance of evolutionary theory (Deniz, 2007), it was found that these students' world views, their understanding of evolutionary theory and their parents educational levels were key factors in acceptance of biological evolution but not at the exclusion of other conceptual views (individual as well as cultural). Interpretations of the Qur'an dominate individual and Turkish societal thinking about biological evolution in much the same way literal and fundamental interpretations of the Bible dominates some Christian thinking about evolution. It is beyond the scope of this chapter to investigate these cultural relationships, but suffice to say cultural values and belief systems are clearly important in the development of a sensitive approach to the teaching and learning of evolution: a cornerstone of the geological sciences and a testable explanation for the 'grandeur' of life phenomena on this planet.

This chapter is organised into the following sections:

- A New Zealand case study for teaching evolution in a national curriculum
- Findings for different age groups for GeoVAT questions 1 and 3
- Chapter Summary

Connections between geological science and evolution within a teaching and learning framework are examined and research question 2 is addressed: How do students aged between 12 and 40 years develop their conceptions of evolution and the fossil record, geological time and 3-D geological structures? This chapter describes and discusses the results of the GeoVAT questionnaire (Appendix 5) given to students of different ages and educational systems and the conceptions they hold about the evolution of life and aspects of the fossil record. Figures 10.1 and 10.2 in Appendix 6 illustrate typical conceptions held by students aged 16 years for evolution. A New Zealand case study of the status for evolution in a national curriculum is presented. It builds on the work of Dodick, (2002a; 2007) and Dodick and Orion, (2003b). In particular, Dodick (2007) stresses the use of the fossil record as an aid to 'cement' the links between geological time and biological evolution. This is a key teaching and learning challenge for Biology curricula developers and teachers.

Currently, Biology curricula in general focus on abstract ideas of micro-evolutionary population gene frequency changes rather than the paleontological and paleoecological issues. In other words there is little curriculum statement recognition of morphological change through time and the linkage between natural selection and constantly changing environments (biological and physical) at taxonomic levels higher than the species level. It is likely a mistake to justify absence of geological time and the fossil record from curricula on the grounds that it is too difficult or abstract for secondary school students – it effectively removes the opportunity for students to develop their conceptual awareness of time, biological evolution and the fossil record. These connections are also best addressed by use of field work and real fossil specimens. Data result Tables 10.2 to 10.8 for this chapter are presented in Appendix 6.

10.2 New Zealand Case Study for Teaching Evolution in a National Curriculum: A Summary

This case study (See Appendix 6 for full details) illustrates how biological evolution is not fully connected with the geological sciences. In total, it amounts to a relatively small part (maximum of 20% to 25%) of a full year course in Year 13 Biology. Geological time, cladistics and the fossil record are the grist with which we understand the evolution and history of life on this planet, but this is not fully committed to the New Zealand (and many other countries) Biology curricula (see Chapters 3 and 9). The reasons for this are likely to be found in the political histories of curriculum evolution, notions of what constitutes subject disciplines, teacher training and the driving forces of teaching for student assessment and national qualifications. Examination questions are designed to enable students to demonstrate their level of understanding through the use of descriptive, explanatory and discursive or discussion type questions. Discussion type questions involve critical thinking and the linking of related ideas. This demands higher cognitive skills.

Typical Achievement Standard examination questions on evolution cover aspects of trends and patterns in human evolution but fails to significantly connect with the fossil record and geological time: the key drivers for environmental change and in turn, ultimately, macroevolution. Students in New Zealand who learn Biology are exposed to serious evolutionary thinking, mechanisms and evidence only at ages 16 to 19 years and are likely to finish their formal schooling with a biased (via limitations of standards criteria) and hazy understanding of this crucial area of scientific literacy. In essence, they do not gain any depth of the conceptual connections between geological time, the fossil record and evolution. As stated by Dodick and Orion (2003b), there is convincing argument for Biology teachers and curriculum developers to more fully acknowledge the ‘mutualism’ of the fossil record and geology for a better conceptual understanding of biological evolution and the nature of science (NOS) or ‘how science works”.

> *“We suggest that implementing a unit that integrates the fossil record (macroevolution) and the genetic mechanism of evolution might alleviate many of the problems that students have in understanding this complex topic. If non-biology majors’ benefit from this exposure there is good reason to think that biology students will also benefit from it”* (Dodick & Orion, 2003b. p.189).

Producing a conceptual change in curriculum development and implementation is a challenge not easily overcome. This would involve the whole process of change in infra structure, intentions and satisfying of the general ‘Posnerian’ conditions for conceptual change.

The current NZ 2010 Biology curriculum (1994 version) did not, and the 2007 revisions have yet to action (by way of assessment standards), the crucial connection between the fossil record, geological time and the study of paleontology and paleoecology. In so doing, a more sophisticated understanding of the origin and evolution of New Zealand's biota is possible. Indeed, although in the 'Living World' strand of the revised 2007 NZ national Science curriculum evolution is an acknowledged connecting thread through all year levels, it is not yet specifically and formally expressed as an assessment standard. Note that the NZ Science curriculum assesses four strands of science: Physics, Chemistry, Biology and Planet Earth and Beyond. The revised 2007 Biology curriculum is yet to be fully 'unpacked' to reveal the intent and content of the achievement objectives. However, revisionary 2009 models of Biology assessment content would suggest that fossils and geological time are not seriously acknowledged in the national Science curriculum and is not part of the Biology assessment standards, which focus on variation and change in Year 11 and evolutionary processes, speciation and human evolution at Year 13.

10.3 Rationale for the GeoVAT Earth Science and Evolution Survey Questionnaire

The following section investigates responses from selected evolution related questions (Questions 1 and 3) from the GeoVAT instrument (See Appendix 5). These questions specifically address the evolution and fossil record aspect of research question 2.

These research questions elicit respondent conceptions (and perceptions) about fossils (Section A.1 of the questionnaire) and fossils and time (Section B.3 of the questionnaire). The intention was to investigate how students of different ages firstly, think about fossils, and secondly how they think about geological time as related to key bio/geological events. Trend's research (2001) indicates that the in-service education of primary teachers in the UK (of similar age to the American University of Beirut (UB) and pre-service primary trainees data presented here), do not have a "secure grasp of deep time, either in absolute or relative terms" (Trend, 2001, p.215). There appears to be a general tendency to lump relative geological events into large chunks: 'incomprehensibly very old', 'old' and 'young', in what Trend (2001) calls "extremely ancient", moderately ancient" and less ancient" (p.191). Links between evolution of life as seen through the fossil record and its geological context was not explored in Trend's work. Libarkin, Kurdziel and Anderson (2007) in their work on

American College age students, suggests that there is a disconnection between conceptions of absolute geological time frames with biological events making a more sophisticated comprehension and conception of biological evolution difficult. They go on to suggest that developing teaching strategies for an earlier teaching of geological time would be beneficial for building stronger connections between geological time and biological and geological events. In other words, building connections between scale of time and relative positioning (in terms of relative events) in a similar manner to that of other scientific concepts such as atomic theory, energy and genetics is likely to accelerate and promote the conceptual development of a scientific understanding of geological time and the place of the fossil record within this framework. This in turn would promote a deeper conceptualisation of biological evolution. In effect, student conceptual developmental experiences for geological time, paleoecology and their connection to evolution is too little and too late.

10.4 American University of Beirut (AUB) Primary School Teacher Trainees: Conceptualisations of Evolution, Fossils and Geological Time

This small, all female student class sample of primary teacher trainees had an average age of 19 years and 5 months. Although 52% (n=19) of this cohort were born in Lebanon, other students were born in Spain, Saudi Arabia, Kuwait, Jordan and the USA. Around 68% were affiliated to Islam with the remainder either Christian or atheist. The dominantly favoured school subjects were English, Mathematics and Biology.

10.4.1 GeoVAT Question 1 Result Interpretations for AUB Primary School Trainees: Ideas about Fossils

As discussed in Chapter 4 it took centuries for an accurate conceptual understanding and acceptance of what fossils are. Questions 1 to 10 (Figure 10.3, Appendix 6) are intended to probe student conceptions of fossils. It is clear that fossils are not by this cohort, conceived as being tricks of the 'devil', failed creations of a God or grown from seeds in rocks. These are 14th century conceptions of fossils. Question 4 appears to have posed more of a challenge perhaps due to unclear understandings of what was meant by 'accident of nature' or by genuine lack of conception of how fossils form. It is clear that the majority of respondents understood fossils as being the preserved remains of once living organisms, but it is less clear as to whether they are the preserved remains of only **extinct** organisms. In other words, 21% of respondents thought that fossils can **only** be the preserved remains extinct organisms. This raises the conceptual difficulty of deciding when is a once living organism, a fossil? Of course, many organisms are still extant and are preserved as fossils because of the arbitrary time constraint of around 10,000 years. It is significant that all respondents considered fossils to be important and interesting and many respondents explained why in question 1c. Figure 9.4 shows the response agreements for GeoVAT Question 1.

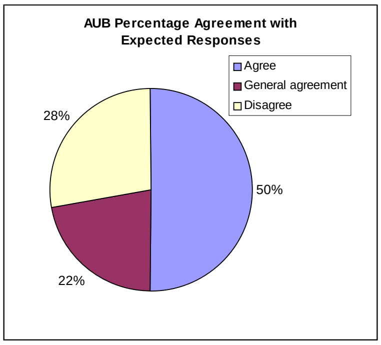


Figure 10.4. AUB response summary for question 1 of GeoVAT.

The majority of these primary teacher trainees (74%) incorrectly thought that Charles Darwin was the first to think of evolution. Perhaps this choice suggests that there is a lack of general knowledge of the history of science and particularly the history of the scientific theory of evolution. Perhaps it also indicates a lack of understanding of how Science builds on what has gone before. It is surprising that 26% of this small study group think that fossils do not support the fact and scientific theory of evolution. It is not known why some respondents think this: perhaps it is a denial of evidence that is too powerful to deal with when in conflict with established concepts. The fact that humans have evolved from ancestral apes is also only agreed with by 42% of the respondents. To have a scientific view of this requires an understanding of what 'apes' are from a biological perspective. It is likely that many students in this cohort do not have this background and 'apes' will produce an emotional response rather than viewed from within a biological context. For some reason there are those that want to place Homo sapiens separate from the rest of the animal kingdom and hypothetically, these students may see people not as 'apes' but as humans. It is a little surprising that 47% had little idea of the age of the oldest fossils currently known and of these, none ventured to state their own guess at a numerical age. Perhaps they just had no idea (see Chapter 6 for discussion of student perceptions of various scales).

Only 37% of respondents correctly identified birds as the modern descendants of dinosaurian ancestors. The reasons for this is worthy of considerable more investigation. Of even more concern was the 26% of respondents who correctly identified DNA as being the universal protein coding genetic molecule of all living organisms. Perhaps this cohort were non-biology students but it is a surprising result given that global Biology curricula focus on molecular biology and the central role DNA plays in the maintenance and evolution of life.

Questions 16 and 17 are intended to probe understanding of the rate of speciation in terms of the concepts of gradualism and punctuationism. Responses confirm that most respondents in this cohort consider the speed of speciation to be a slow gradual process (95%) with very few (26%) considering that speciation as recorded in the fossil record consists of a long period of stasis followed by a short period of time in which new species appear. Of course no respondent considered that the Earth was made in six or seven days. Few primary school trainees (and secondary) will ever reach this level of conceptualisation of the fossil record and as Dodick (2003c) points out, students of all ages have difficulty with learning about evolution.

Questions 12 and 18 relate to concepts of the Nature of Science. All respondents acceptably considered that a ‘scientific theory’ is not just a guess and only 11% conceived the ‘scientific method’ to be only a controlled testing of hypotheses. Science as a discipline of learning seems to be conceived by this cohort as something more that just experiments.

The dendrogram in Figure 10.5 is derived from a multivariate clustering by minimum variance technique (Kovach, 1998) of responses to Q3 on fossils and time. True/false responses are considered equivalent to presence/absence data. There appears to be four clusters of responses:

Cluster 1 = Questions 13, 15 and 16

Cluster 2 = Question 10

Cluster 3 = Questions 6, 4, 18, 7, 12, 2,1, 3 and 14

Cluster 4 = Questions 5, 17, 11, 8, and 9.

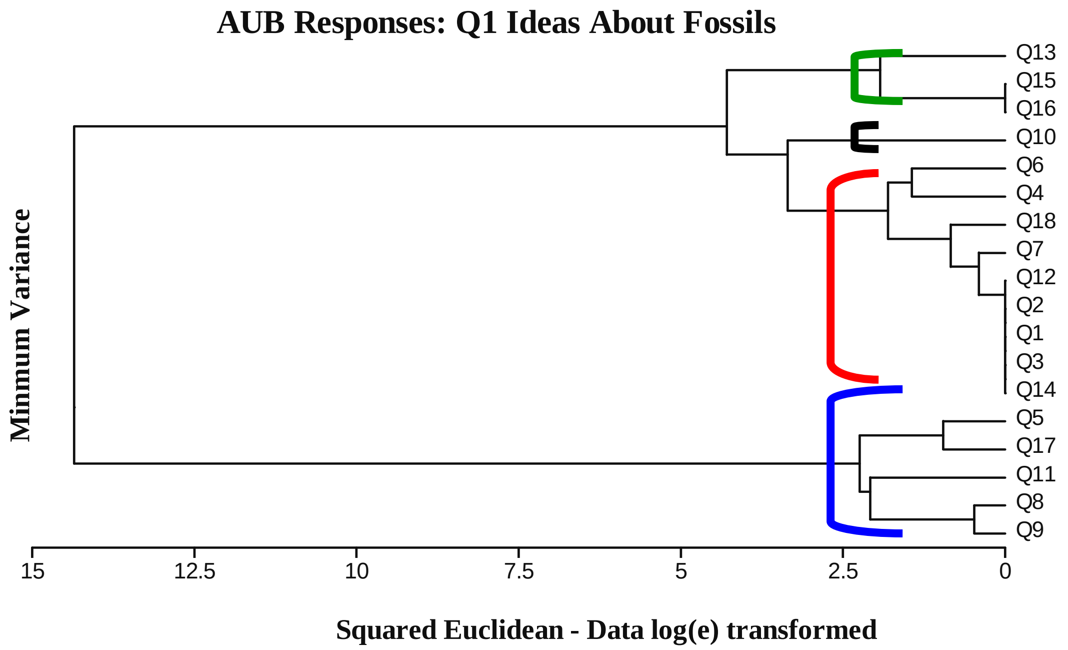


Figure 10.5. Dendrogram clusters for AUB primary school trainees. Clusters are those questions with equal distributions of true/false responses and are colour coded in Figure 9.3 in Appendix 6.

10.4.2 Summary

Although an understanding of fossils is generally considered to be important and interesting there are perceptual and conceptual 'scales of time' difficulties. There are also gaps in the understanding of the rates of speciation, DNA as a universal self replicating gene coding molecule, and difficulties about the contextual meanings of key words such as 'ape' and dinosaur. Conceptualising the place of common ancestry in its correct evolutionary context is an area of future research. Understanding 'rate of change' is also a difficulty for high school and university students not only in the geological sciences but also in physical and chemical science.

Students appear to understand what fossils are or are not, but have confused ideas on the detail of their interpretation and usefulness. For example, they cannot put an actual age to the oldest fossils known and have trouble reconciling people as 'apes' in much the same way as "people are not animals" (NZ Year 12 Biology student).

All responses suggested that all students understood Science to be more than just a guessing game but that around 26% did not consider fossils to support the fact and scientific theory of biological evolution. As Catley (2005) correctly points out, establishing and developing a pedagogy for teaching systematics, phylogeny and cladistics would go a long way to enable a better conceptualisation of evolution and especially the linkage between micro and macro evolution.

10.5 Question 3 Fossils and Time: AUB Primary Trainee Responses

Figure 10.6 in Appendix 6 shows the responses to student perceptions of relative bio/geological events for GeoVAT question 3. Events are arranged in time succession rather than in question order. There is considerable variation in the number of responses for each event perhaps indicating lack of confidence in being able to provide a meaningful response or a lack of understanding of the question. For example, the large variation in responses to question one suggests either an inability to properly scale the event or disinterest. 'Saboteurs' are not unknown in questionnaires and clearly a response of "a million million years ago" for the development of plate tectonic theory is either a sabotage or disinterest. Even with a thousand response returns, there will always be the outrageous. In any case, conceptualisation and perception of geological time is analogous in difficulty to the scale of atomic and subatomic particles in chemistry, and gravitational forces in physics.

10.5.1 Discussion of AUB Primary Trainee Results for GeoVAT Question 3

Responses reveal a number of issues that support the work of other researchers (Trend, 2000, 2001a, 2001b; Dodick, 2000b; Dodick & Orion, 2003c). It is curious that the majority of responses considered the extinction of the woolly mammoths to have occurred 1 million to 1 billion years ago. This suggests that this cohort either had never heard of woolly mammoths or had no idea when they became extinct or did not care. It seems that if students do not know then they opt for the oldest age category or randomly guess. For this cohort, they probably just did not know.

The time for the extinction of the dinosaurs elicited some interesting responses. Ignoring the extremities, these students significantly underestimated the extinction time. Perhaps 100,000 years to a million years ago is a perceptual boundary to be used when the answer is unknown: ten million is perhaps perceived the same as one million (Trend, 2005). As exposed in Chapter 6 when an events actual time is unknown there is a reversion to an internalised relative time scale based on experiential and innate senses of time. It seems as if anything goes if the actual answer is not known and there appears to be no ‘cross referencing’ of decisions by looking carefully and re rereading the time category relativities. Like the extinction time of the dinosaurs, these primary teacher trainee respondents underestimated the time of the Ice Age. Although in this case students underestimated the relative timing, this is in line with other researchers’ findings (Dodick, 2005; Noonan, 1999; White, 2004) where the implication was that there is often an overestimation of an events timing when ‘the answer’ is unknown. This exaggeration of relative timing as being over estimated or underestimated is likely to be related to the experiences and knowledge of the student and the kind of events timing being estimated. For example it is more likely that students will underestimate the timing of ‘The Ice Age’ and overestimate the timing of the ‘first appearance of the birds’. In other words degree of estimation is likely to be related to the specific event in question and its position on an individual’s axiological, empirical and organisational point of view. Added to this is the nature and extent of an individual’s formal education.

In this cohort, fifty percent of the event timing questions were incorrect with the maximum percentage being correctly answered was 40%: for the appearance of the first volcanoes. Only a third of the respondents knew (understood?) the correct relative timing for the formation of the Moon. The formation of the Sun is clearly overestimated and considered to be more than a billion billion years old suggesting that it is so ancient that “you cannot say” and that a billion billion is as old as you can get: and this despite the fact that the universe itself is only 12 to 15 billion years old! For many students, the universe began when the Earth began and that all the stars that can be seen today are all the same age and the earth is the same as them. This also despite the fact that the Milky Way galaxy has stars of many different ages in it. Respondents overestimate the age of the Milky Way galaxy, the Big Bang and the beginning of time. These events are lumped together into what Trend (2001) says is “extremely ancient”. Not beyond comprehension but beyond the existing experiences of these students. Respondents also overestimated the age of the formation of the

Earth’s crust as being more than 5 billion years old. Few students could correctly order the first appearances of trees, land animals or fish. No responses were recorded for the B and D acceptable time categories.

10.6 New Zealand Secondary Teacher Trainee Ideas About Fossils

This cohort of University of Canterbury (UC) secondary school teacher trainees had an average age of 22 years. Twenty two is a relatively young age for a postgraduate one year teacher training course student who intends to enter the secondary school teaching service in New Zealand. An average is more like 26 years being boosted by workers who have changed direction. Responses are outlined and then discussed.

10.6.1 GeoVAT Question 1 Findings for NZ Secondary Teacher Trainees

This section begins with question 2 of section A of the GeoVAT questionnaire where students were asked to write an explanation for any of the two statements from question 1 that they thought were true. Writing explanations often reveals conceptual status. Table 10.1 shows typical secondary teacher trainee explanations and Figures 10.7 and 10.8 in Appendix 6 show the distribution of responses to questions 1 and 3 respectively. Tables 10.2, 10.3 and 10.5 in Appendix 6 compare UC secondary teacher trainee results to other cohorts for Q1: ideas about fossils.

Table 10.1. University of Canterbury (UC) secondary trainee responses to Q. 2 Section A of GeoVAT.

Statement	Explanation of Statement
5	(a) Because oxygen stops it from decomposing
	(b) Are skeletons that have been preserved
	(c)Because I was told
	(d) Fossilisation processes happen all the time
	(e) Impressions left when the rock solidified around a dead creature
7	(a) Important for scientific study
	(b) Proves that organisms once existed that don't today
	(c) Carbon dating gives age of fossils
10	Humans evolved from apes because of preserved skeletons and dating
11	Found bacteria so must be old
12	A scientific theory is a guess and we don't know what the future will bring
13	Supported by the fossil record
15	All organisms have DNA with ATC and G.
16	Quoted by S. Gould in Punctuated equilibrium and supported by the fossil record
17	Slow history of evolution by gradual change
18	You can't prove a hypothesis can only use evidence as support or not

Section A, Question 3 of the GeoVAT questionnaire asks students to write an explanation for "why are fossils found at the tops of mountains". The following describes typical explanations from these 22 year old students.

- "Plate tectonics pushed the sea floor up
- Weathering and erosion exposed them
- Mountains must have been immersed long ago
- Plate tectonics pushed up fossils from lower levels
- Lots of changes mountain tops may have been lakes or swamps
- Once underwater
- Different levels of ocean, movement and plate tectonics".

Section B

Question 1 (a) asks students for their observations of illustrative evolutionary changes that have occurred in the fossil feet (of horses) through a conformable sedimentary sequence. Typical responses include:

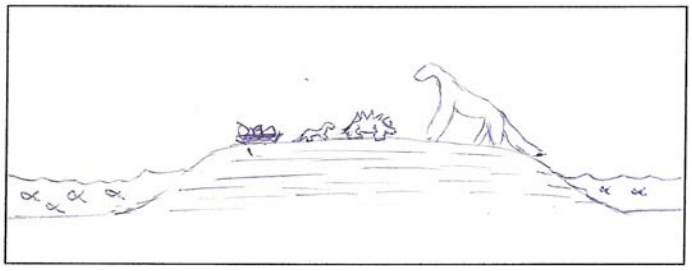
- "Changes are evident through time
- Feet become more complex

- Evolved! Become more adaptable to conditions – increase in toes changing massively 4 legged to two legged.
- Evolved from many toes through 3 to a foot only.
- The foot went from having four toes too having a single toe or hoof like a horse).
- Between layer 1 and 4 the foot has reduced the number of toes
- Entire foot has eroded to end up with one toe.
- Loss of toes
- Small bones disappear except the middle one
- Reduced to a single flipper type structure

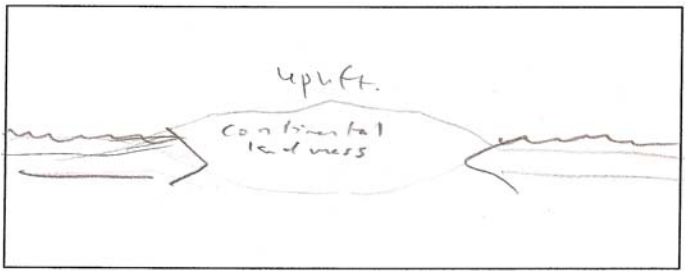
Question 1 (b) asks students to provide two possible reasons for the absence of fossils. These are the responses:

- "Unfavourable environmental change
- Predators killed off all the species
- Species extinction from climatic environmental change from asteroid impact
- Fossils not deposited in that specific area
- There are no extinct generations or no change in atmosphere
- The rock may be too soft
- Species did not live in this area and unfavourable conditions
- Rock contained chemicals that eroded fossils
- Period of volcanic activity where layers were laid very quickly
- Animals moved to a different area. Wrong weather conditions for fossils
- Could be under ice or could be a rock type that does not preserve fossils
- Erosion (multiply forms) and a landslide
- Too long ago, fossils have disintegrated or this animal did not exist then".

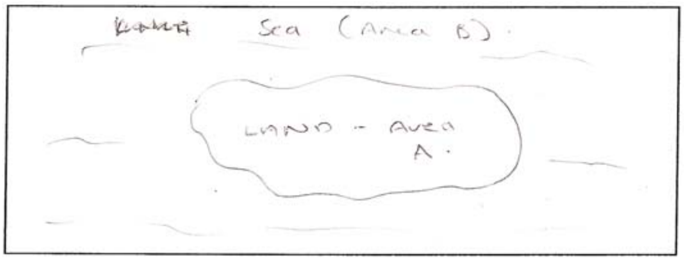
Questions 2 (a) and (b) investigates student ability to translate plan view into cross section (2a) and to express connections between fossil and living ecologies (2b). In this case, it is an island in which there is an area of dinosaur eggs and another with a dinosaur skeleton (See Appendix 5). Figure 10.9 shows some typical responses.



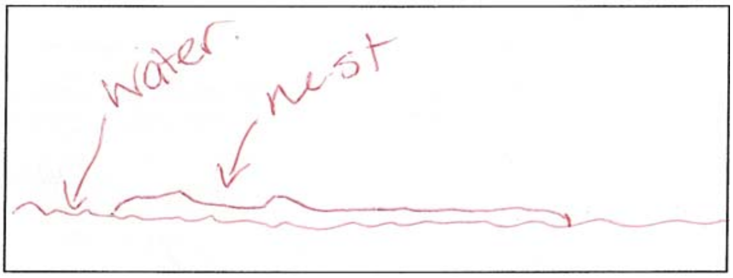
A


uplift.

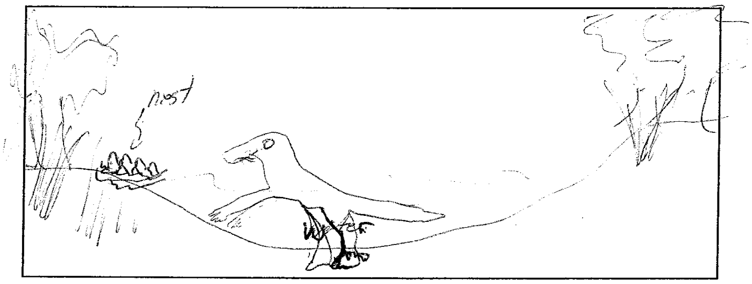
B


Sea (Area B)
LAND - Area A.

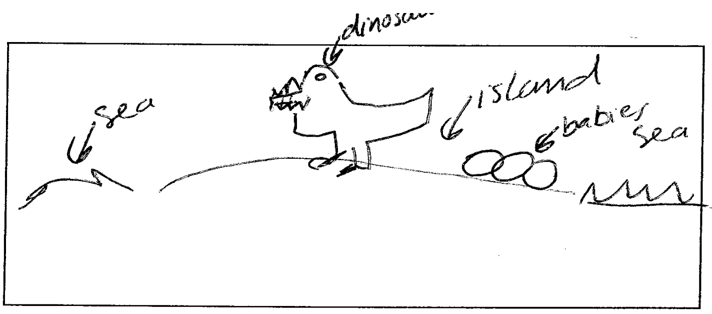
C


water.
nest

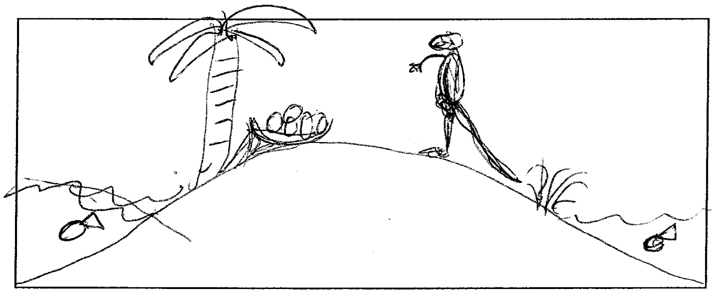
D


nest
water

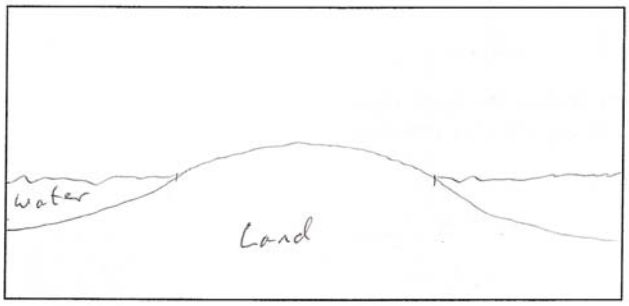
E


sea
island
babies
sea

F



G



H

Figure 10.9. UC secondary school trainee responses to Section B, question 2a.

Question 2(c) intends to investigate explanatory conceptions of alternating marine and terrestrial geological environments as expressed in the fossil record. The following are the responses received.

- "Caused by sea level change and rising land
- Different levels of ocean, movement and formation of mountains – plate tectonics.
- They were once underwater
- The island was flooded now and then but when the waters receded new dinosaurs migrated to the island
- Shows periods of the Ice Age when the sea level rose and fell
- Area was close to the ocean and when water level rose the marine sediments were deposited and when the water level fell it became dry land.
- Sea once flowed through the area but due to plate tectonics the sea no longer flowed but instead a river did as the Earth shifted".

Question 2d asks students for their perceptions of what the world would look like and sound like when it was first formed compared with today. The following outlines what these adult secondary teacher trainees perceived.

First Formed	**Today**
Brown and loud	Green and quiet
Hot, brown and loud	Green blue and loud
Brown and cold	Less trees and loud
Large landmass and quiet	Less land and blue
Green and blue	Blue/green and noisy humans
Green and cold	Green and noisy
No life with lots of earthquakes	Green warm and loud
Volcanoes	Green and quiet
More water and quiet	Colourful and full of sound
Cold and quiet	Green, cool and loud
Hot brown smoke and loud	

10.6.2 Discussion: New Zealand Secondary School Trainee Responses

These responses are from New Zealand secondary school teacher trainees with an average age of 22 years and who last studied geology in their Year 11 class, seven years previously. Although a small cohort, many geological and scalar misconceptions are revealed which appear to be typical responses.

One significant difference between the AUB primary trainees and UC secondary trainees is that the AUB students considered Charles Darwin to be the first to think of evolution (74%) whereas only 27% of the UC students did. Is there a difficulty in interpreting what is meant by the question or do the AUB students really think that the theory of evolution began with Charles Darwin, and if they do why? Table 9.2 in Appendix 6 shows a comparison of responses between UC and AUB for ideas about fossils for the same age and teacher trainees but from different 'cultures'.

Clearly, modern interpretations of what fossils are override the rather ancient concepts of fossils as suggested by statements 1 to 4. However, there are still ideas present (around 20%), that fossils are considered to be just accidents ('sports') of nature rather than the actual remains or traces of once living organisms. Whether this is a misunderstanding of the word “accident” or an actual denial or even ignorance of the correct origin of fossils requires further study. Question 9 indicates a point of contrast between the two cohorts. Although there are a small proportion of responses that indicate students’ consider Charles Darwin to be the first to **think** of evolution (he wasn’t) for the UC cohort, the AUB cohort is significantly different: the majority think this was correct. Perhaps this indicates a lack of teaching about the history of science and how knowledge is built, or a cultural divide? Question 12 also indicates a point of contrast for the nature of science and one for which the reasons are unknown.

Questions 15 to 17 ask about a modern interpretation of rates of evolution, scale and the genetic component of evolutionary processes. The difference between the two cohorts for understanding that all living things do share the same basic DNA coding system may partly be explained by misinterpretation of “DNA coding system”. AUB students may have interpreted this to mean that because animals are different their DNA is different (which makes them different organisms) rather than understanding the broader meaning of DNA coding for the manufacture of proteins in the form of the ‘base pairs’ Guanine, Adenine, Thymine and Cytosine. Although both cohorts consider the speed of evolutionary speciation to be slow fewer UC students thought so. This finding suggests that teaching of punctuationism and gradualism as concepts in rates of evolution based on the evidence of the fossil record in Year 13 Biology courses may have been effective in changing concepts about rates of speciation.

Perceiving and conceptualising rates of evolution are fraught with difficulties for learners (and teachers) especially when rates of change, change at changing rates. Applying the concept of changing rates of change in a geological sense requires considerable cognitive development and experiences that few students get to develop. Question 18 is revealing and asks about the nature of science. It seems that AUB students think that ‘the scientific method’ is more than just controlled or fair testing of variables where simple relationships between the dependent and independent variables are ‘discovered’. Perhaps (in speculation), this reflects a deeper understanding that the geological and historical sciences require more than the mere testing of variables because the nature of the geological information does not easily lend itself to controlled testing. For example, how do you test the multivariable's involved in explanation of an evolutionary fossil lineage such as Homo sapiens? However, 73% of this UC secondary trainee cohort thinks that a scientific methodology only involves controlled testing. I wonder why? Perhaps this reflects the historical development of science education with a current hierarchical system of science 'subjects' that has evolved from Greek mythology and philosophy.

Question 2 of section A is summarised in Table 10.4 in Appendix 6 and reveals a variety of levels of understanding and ability to express explanations. Explaining concepts is more difficult than merely describing and requires a clear comprehension of the concept and a literacy level that enables expression. Reasoning for question 5 suggests a general lack of depth and superficial reasoning with the exception of two explanations: abiotic environmental factors such as anaerobic conditions, and the concept of burial. These two reasons indicate that some students are aware of conditions needed for fossilisation to occur. Indeed, remains of once living organisms often require these conditions to be preserved in rock. It was interesting that one explanation only considered fossil impressions rather than whole organism fossilisation or a cast. Indeed, the concept and process of fossil casts and moulds are unlikely to have been taught as they do not appear in the New Zealand science curricula except in unit standard 6362 ("Demonstrate an understanding of fossils"). This standard requires an understanding of fossilisation processes, how fossils provide evidence of environmental change and how they provide evidence of evolution through geological time. Nationally however, only 274 students achieved credits from 2003 to 2007 (See Chapter 12). So, there are very few students who know any detail about the processes of fossilisation. As noted earlier, the fossil record and the vitality of palaeontology as an area of learning is a missing link in the teaching of Biology, which is almost exclusively neontological (study of living organisms) rather than paleontological (study of the fossil record).

Explanations for question 7 suggest that students realise that the study of fossils is important for furthering scientific knowledge (a generic statement for all scientific endeavours) and that fossils provide concrete evidence of species extinctions. Of more concern is the one response that indicates a lack of understanding of radiometric dating and that fossils are only dated using isotopic carbon. Anecdotally, most secondary students I talk to are wholly ignorant of the many other radioisotope dating techniques such as Uranium to Lead decay, and rarely comprehend the limitations of using carbon dating analysis and even more rarely, connect relative dating and magneto-chronostratigraphy with dating fossils. Teaching radiometric dating in a geological context does not appear specifically in any assessment standard in New Zealand and therefore is simply not taught except at a senior physics level. When radiometric dating is known about it is most commonly restricted to Carbon -14 dating which has a limited application to around 50,000 years. The concept of cross referencing data does not seem to be evident in any response. After assessing hundreds of investigations for planning, doing, analysing and reporting, only rarely do student reports indicate the importance of cross referencing an experiment with independent methods of gathering data. Dating fossils is not dependent on only one line of evidence but many (Dawkins, 2009).

Of the remaining explanations for a student-selected true statement (it might actually be a false statement, but in their view is true) only one response was gathered for each. However, the spread of explanations suggest a number of possibly common misconceptions. For example, the misconception of a scientific theory as just a guess and the implication that Science cannot predict the future suggests that at least one student cannot separate the predictive power of science investigation as based on evidence and falsification from an unknown and unpredictive future. At least one student had read about punctuated equilbria as an interpretation of the scale of geological time and its connection with the fossil record and speciation events. An explanation given by one student to justify why question A1.17 is true revealed misconceptions about what the meaning of evolution. This student confused geological time as the evolutionary event rather than the populational speciation event. In other words, there was confusion between the long period of time (gradualism) as the producer of new species rather than the speciation events themselves which occur over much shorter relative geological time periods (punctuationism).

The single response to question A1.18 suggests that this student considers the scientific method to be based on testing and proving hypotheses but that science can only use evidence as support rather than as an absolute proof. Perhaps this student is unclear of what is meant by ‘controlled testing’ but does appear to recognise some limitations of the nature of science and its methodology as a way of knowing about the world. It is unfortunate that there were no more responses from this cohort.

Responses to question 3 from **section A** indicate that although some students accurately conceive tectonic forces as a cause of mountains which carries the fossils up with them there remain many misconceptions because many students fail to connect the origin of fossils (often marine in lifestyle) from the origin of mountains. There is a tendency to focus on one issue: fossils or mountains. Many responses implied that the fossils were simply exposed by erosion with the fossils already there at height, with no uplifting. One response for example, suggests that the fossils were formed in place at the top of a mountain in lakes or swamps as if the mountains were always there, and another response implied that the mountains were once under water as if they were already made but waiting to become mountains as seen today. Clearly, some student concepts about the origin of mountains and the existence of fossils at the top of them have not benefitted from the ideas of James Hutton since the mid 1700’s.

For question 1a of GeoVAT Section B all responses recognise that there is a reduction in the number of toes, but only one response links this with geological time through the conformable stratigraphic sequence. But they were not asked to make this link, merely describe what changes they observe in the skeletal remains. Question 1b really asks students to link the fossil record with paleoenvironmental change as explanation for the absence of fossils after stratum 4 and many responses imply an understanding of this linkage albeit for example, blaming predators for killing all the fossil animals (horses) is rather unlikely. However, only one of the 13 responses implied the idea of species extinction: a key fact of biological evolution and a concept that is rarely taught in depth at secondary school, and in Biology courses is often perceived as subservient to the ‘progressive evolution’ of a species to a ‘better and more successful model’ rather than to extinction. Future investigations for the reasons for this may offer insights into cultural biases of the nature of science.

Responses to question 2 (a) Section B indicate a range of abilities of these graduate teacher trainees in translating plan view to cross sectional view. Sample C (Figure

10.9) for example simply copies the plan view. The conceptual and perceptual difficulty exposed in this question is that of what to do with boundaries when at depth, and how to mentally rotate structures. These are spatial-visual abilities needed for 3-D visualisation of geological structures (See Chapters 6 and 7). Sample A (Figure 10.9) is the only response that accurately shows these 'vertical' depth boundaries. B and D show the most common conceptualisation of cross sections as an island 'floating' on air as if there is nothing underneath. Similar problems occur when students begin to learn how to draw geological maps and cross sections. Response B seems to indicate that this student has tried to copy a visual image of continental drift boundaries but was unable to visualise what was underneath the 'continental island'. The idea of invoking plate tectonics suggests that students have little understanding of the tempo and rate of geological time and use plate tectonics as a causal catchall for any geological change or process. Response G (Figure 10.9) is interesting because it seems to display a connection with a rotational visual spatialisation difficulty where the land and sea are mirror images. This also shows an inability to draw depth boundaries.

Question 2c shows a sedimentary sequence of rock types that were deposited in a summer season but under different geological environments: terrestrial and marine. It seems that students did not read the information supplied with the question and failed to connect the appearance of fossil skeletal remains with the summer season in a terrestrial environment and the transgression of the sea in which there are no fossil dinosaurs. Although there was recognition of possible eustatic changes (climatically controlled sea level changes and possible tectonic rising and lowering of land) as an explanation for the alternation of sediment deposition and the appearance of dinosaur remains, the cyclical nature is not recognised or explained. These responses suggest that students have very little conceptual understanding of the connections between geological environment and sediment deposition.

The intention of question 2 (d) section B is to elicit student imaginations of the early Earth compared with today expressed as a 'look like - sound like' perception. The dominant difference is in the colour. The world is perceived today as green and loud but brown and loud when the Earth first formed implying that the early Earth had no life and full of earthquakes and volcanoes. This is in contrast to today where there is abundant ‘green’ life colour and noise with the implication that life did not arise until much later and that humans make the world noisy.

Question 3 investigates perceptions of timing relativities of major geological and astronomical events. Events are adapted from that of Trend (2001).

10.7 New Zealand Year 12 (16/17 year olds) Responses to GeoVAT

The GeoVAT instrument was also given to a group of New Zealand Year 12 students. These students are in their second to last year of secondary schooling before entering a University and were also a group who were learning Biology, where they first encounter a scientific view of biological evolution (See Chapter 9 for details of the NZ Biology standards). ANOVA analysis comparing the AC Year 12 group with UB and UC groups (Table 10.3 in Appendix 6) indicates that there is no significant difference between responses (F =7.9. p = 0.01 and F crit. = 2.5) for question 1 Section A: True/False ideas about fossils.

In effect this means that in this small sample of teacher trainee graduates from different countries (who are 5 years older and university graduates) responded similarly to questions about their conceptual understanding of fossils to a class of 17 year olds starting out in Biology. This result should not be generalised and applied to larger populations because many variables are not able to be controlled for. This suggests a need for collecting data from a much larger population. Hokayem and BaouJoude (2008) suggest in their study of AUB biology students’ perceptions of evolution, that variables such as epistemological beliefs, perception of religion, science and nature, and perceptions of causality largely control the evolutionary conceptual status of their students. It seems that this cohort of AC 16/17 year old students know what fossils are, and are not, and that 50% of them consider Charles Darwin to be the first to think of evolution. Interestingly, although 90% of these students correctly thought that the oldest fossils were around 3.4 billion years old, the graduate teacher trainees were not so sure. The older students also perceive the scientific method as not just a guess whereas the younger AC students are less sure where a third of them think it is just a guess. The nature of science and its methodologies has recently received more importance in the 2007 NZ curriculum, but teaching it is not so easy (Bickmore, Thompson, Grandy and Tomlin, (2009); Hipkins & Barker, (2005). The 19% of AC Year 12 students who consider the Earth to have been formed in six days are those students who appear to wrestle with their non scientific religious beliefs, and the evidence as shown by rocks, fossils and minerals. Questions 16 and 17 show that all respondents generally think that the appearances of new species are slow and that evolution is a slow process. It is clearly not a common understanding that all living organisms share the same basic DNA coding system for making proteins. Sustainable and effective conceptual change strategies for evolution are a major pedagogic challenge.

Section A question 2 asks for explanations of any two true statements. Here are the responses from AC 16/17 year olds.

Q13 "Dinosaurs that were birds and they evolved and changed
Fossils have naturally evolved to suit environments

Q17 Slow change through time by the rocks they are in

Q7 Knowing the past will help the environmental future
Fossils tell us about the past and the future, and geography
Fossils are dead things compacted and pushed up.
They are amazing to look at and provide insight into history

Q8 Fossils can show us differences in animals
They provide information that is too logical to doubt

Q10 Fossils show we have evolved from apes

Q14 The bible says so.
[The Earth] was formed in 6 days, yes, but I also believe we are evolved from apes. My theory is that the days of God are longer than ones on Earth (We echo them)."

In interpreting these response explanations, it seems that these young students know about fossils, see them as evidence of past life forms and connected to evolution, and that they can be used to understand ancient environments which may have a relevance to future environments. This suggests that some students have independently understood the principle of uniformitarianism without really knowing it. The ontologically and religiously controlled students' responses to Q14 (e.g. "The Earth was made in 6 days .."), indicate conceptual conflicts and dilemmas. On one hand the fossil record is recognised as being concrete evidence of biological evolution but on the other, this can not be easily reconciled with a scientific view of geological time, fossils and evolution without abandoning a religious view. So, a mixture of concepts is employed and one that is echoed in the explanation above as one that accepts the evolution of people from the common ape ancestry, but in a modified view of time.

Section A Question 3 asks for explanation of why fossils can be found at the tops of mountains. Here are some typical responses.

- "Animals died at the tops of mountains
- Died at the tops of mountains, covered by dirt and plants, and rain then washes away the dirt to reveal the fossils.
- I think they were left in the bottom environment at first then new rocks and crust grew around it and slowly got raised to the top as old crust layer falls and new ones grow in place.
- Mountains were originally lower, below sea level. Fossils were placed there, then the mountains rose.
- I believe that the fossils that are found there are from animals that died at the top and /or tectonic plates formed the mountains when they moved
- Mountains rose through the sea carrying living and fossilised creatures up the mountain.
- By plate tectonic movement
- Don't know – perhaps the flood idea is right?"

Apart from literacy issues, these responses reveal a number of typical misconceptions about fossils that are found exposed at the tops of mountains. Many responses fail to connect the origin of the fossils to the location and simply focus on the location. Other responses considered that the mountains were pre-formed and later pushed up by plate tectonics, suggesting that there is little understanding of the bigger picture of sediments, environments, living organisms, death, fossilisation, burial and uplift. Again, it is disturbing that it is not uncommon for responses to be 'fixist', where the fossils were conceived to be already in place at the top of the mountain and had no previous history. Others of course correctly recognise fossils as being exposed at the tops of mountains by erosion. Only one response accepted the information given, where the draining away of a great flood left the fossils exposed at the top of a mountain. At least this individual read the question! It is curious that fossils are nearly always referred to as "**animals** that have died" (and most likely to be dinosaurian) rather than plants or other types such as trace fossils. Micro fossils are never mentioned. In one response it is not explained how fossils were placed at the top of the mountain and then the mountain rose! The conception that mountains are pre-formed or held to have always been a mountain is a powerful one. Once a mountain always a mountain, and this conception may have some connection to the notion of the 'fixicity' and unchanging land, the world, and the things in it.

10.7.1 Section B: Conceptions About the Uses of Fossils (AC Year 12: 16/17 year olds)

Q1. (a) Observations of fossil changes through time. Typical responses are:

- Fossil feet become compressed and eroded away
- Small bones disintegrate over time with layer #4 with only one
- Lost one toe and evolved one large
- Worn down by environmental changes
- More developed in layer one, then worn down by pressure and decomposition
- Long toed foot shortened then became a nub or hoof
- Eaten away by parasites
- Each year there is a greater weight put on the fossil and rock may have broken the bones away
- Loses a toe, becomes smaller and rounder then loses the second toe and becomes smaller and rounder again.

It is interesting that several responses suggest that observable changes in the skeleton are caused by physical factors *in-situ* by breakage, chemical decomposition or compression rather than recognition of any evolutionary change. These responses seem to disconnect the conformable rock sequence from the fossil remains and focus on the individual skeleton remains rather than make a connection with an evolutionary sequence. Given information (See Appendix 5) does however imply that the remains are the same "land animal" but has undergone change. For these responses, if the rock layers are not connected, then the fossil remains are also disconnected so the only way in which the change can be explained is by internal physical or chemical change (or in one case, "parasites") rather than evolutionary change. All responses recognise a physical change in the skeleton but none are connected to time as represented by the rock layers. The paleontological and evolutionary concept at the heart of this question concerns evolutionary trends (Gregory, 2008) but this is well beyond the scope of this thesis (and student and teacher knowledge?) but this notion is at the heart of this question where students must first recognise morphological change and then connect them to geological time as represented by the rock strata.

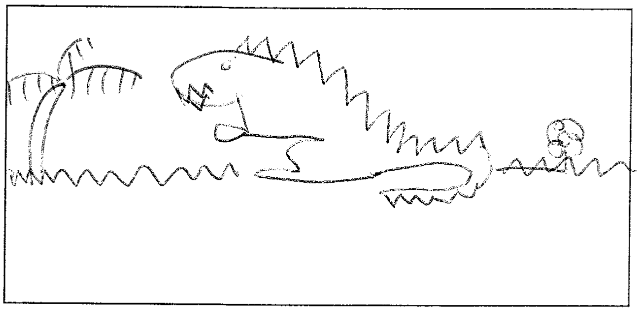
The rationale for question 1.b is derived from Dodick & Orion's (2003 c; 2003c) work on investigating the understanding of geological time, which in turn has been derived and adapted from Montangero's work on diachronic thinking (see Chapter 5). This question requires the conceptual integration of transformation, temporal organisation and interstage linkage abilities and is therefore of a higher thinking order than question 2c which requires only transformative diachronic skills. Here, only a sequence of change is observed, recognised and described, but one where the present is linked with the past. It seems that most responses of these 16/17 year olds manage a transformative recognition of skeletal change but are unable to integrate this with the complexity of a stratal rock sequence (and therefore geological time), as a causal relationship. Recognition and explanation of relationships is a difficult task for this age group as well as those students 4 to 5 years older. In other words, these students are not yet ready to link observable change with the abstract idea of geological time so that the development of diachronic thinking skills seems to be represented here in a developmental and formative way. More research on defining at what age students are able to make these higher order linkages remains to be investigated. I suspect that this integrated diachronic linkage ability (understanding observations that act through time), happens generally much later in life and well beyond the school gate.

Question 1.b Section B asks for an explanation for the absence of fossil bones after layer 4. This also requires the ability to integrate diachronic thinking, in particular, causal relationships of fossilisation with unobservable environments and geological processes. To answer this question demands the linkage between the stratal rock sequences as representing passage of time with the occurrence of skeletal remains within each rock layer. Here are some typical responses.

- "Animals moved on or became extinct
- Bones are completely worn away as species and environments change
- The animals migrated
- They were caught in a landslide
- Erosion removed the top layers and were then replaced
- Things stopped dying
- Hot lava destroyed bones that remained
- Caught in a landslide
- Worn away over time".

These responses suggest that those students, who are unable to apply integrated diachronic thinking skills to a sedimentary rock sequence, invoke the idea that the fossils were somehow removed *in situ* by chemical or mechanical means, for example "worn away over time" or "destroyed by lava". These responses indicate that there is no cognitive connection (for this question) between the origin of the fossil as a once living organism and its preservation in the rock record. Although students know what fossils are, there is little connection with it having once had a life in a *paleo*environment. Fossils did indeed once have a life. This is another level of diachronic thinking that is worthy of further investigation. On the other hand, responses suggest that many students of 16/17 years old do understand that the absence of fossils in a stratal rock sequence **is** time related because the animal "moved on" (migrated) or "became extinct" (not in existence) and therefore could not be preserved.

Figure 10.10 shows two Year 12 responses to **question 2a.** Similar to the UC teacher trainees, these responses show an inability to rotate the scene vertically through 90^0 and an inability to visualise boundaries at depth.



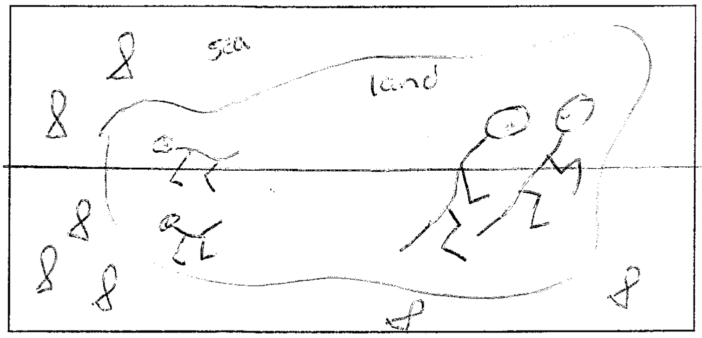


Figure 10.10. AC Year 12 responses to Section B, question 2a.

Only three responses were received for **question 2b**. This question asks for an explanation of the presence of dinosaur eggs and adults on this island. These are the responses;

- "Plenty of food so dinosaurs did not have to travel far. This helps them multiply better
- This was their territory
- Has a "nesting area" (given info on the diagram).

This question requires a transformative diachronic ability where students need to conceptualise the life of the fossil through time. Although there is little information given, these responses do indicate a conceptual status from being able to connect fossils as once living organisms (first response) living in an environment in which they had a "territory" and were successful at reproduction.

There were no responses for **question 2c.** Perhaps this required too much reading and interpretation.

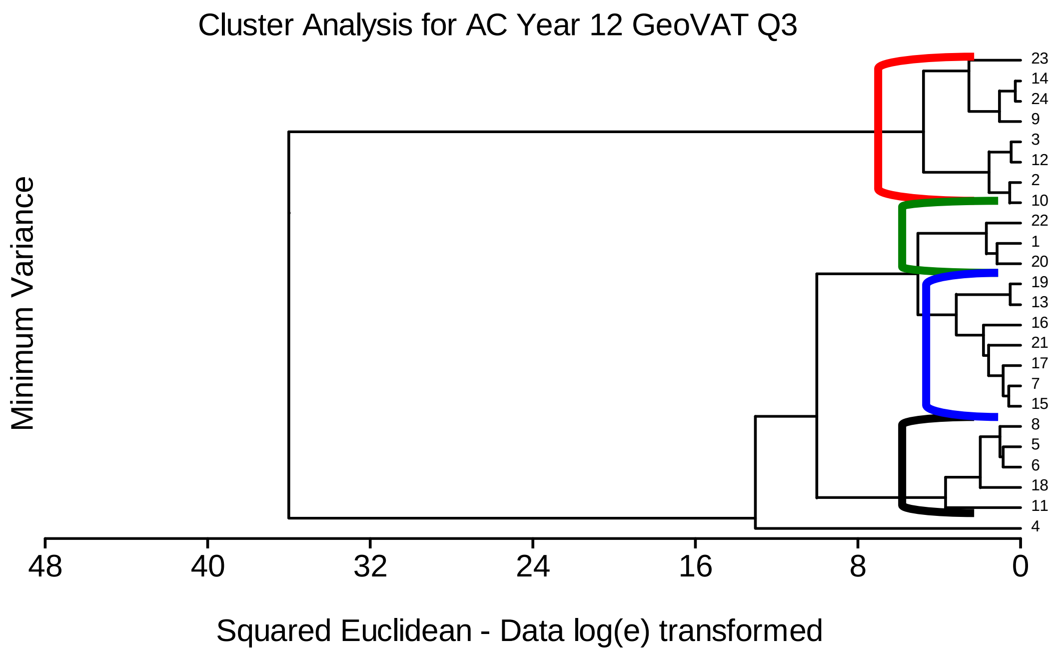
Question 2d Section B.

First Formed	**Today**
Deserted and quiet	Green and Loud
Smaller and rumbly	Bigger with Birds
Brown with dinosaurs	Cold with trees
Hot and quiet	Cold with humans
A large ball with no animals	Large and loud
No forests, just nature	Smog and cold
Bigger and shaking	Less forest and noisy
No water and quiet	Green with humans
Bare	Green with birds and people
Red	Green and loud
Brown	

An interpretation of responses to question 2d suggest that this cohort perceives that when the Earth was first formed there was no life, it was hot, brown and quiet compared with today where it is green (the colour of life?), noisy and teeming with life. Noise is apparently the indicator of life today which was absent when first formed. A common perception within all age groups indicates that the early Earth was dominated by physical phenomena but today it is dominated by organic phenomena mostly people and noise.

Placing geological events and ideas about fossils into relative times proved to be equally difficult for Year 12 students (Table 10.4 and Figure 10.11, Appendix 6). Similar patterns of time overestimation and underestimation occur as in other age groups. For example, despite there being no event older than 13 billion years (age of the Universe), most students place this event correctly as the oldest event but not relative to all other events. It seems to be treated in isolation from relativity. Questions 9, 3, 24, 23 and 14 (Formation of the Sun, Earth, Milky Way galaxy, beginning of time and the Big Bang are all recorded as equal in age but estimated as more than a million million years old - several orders of magnitude greater than they are. It is as if these events are the oldest known so therefore they belong in the oldest category regardless of relativity to the age ranges given. Do they take any notice of instructions? Only 21% of responses were able to give the correct age of the oldest rocks found in NZ (Question 22) suggesting there is little knowledge and perception of geological time. It seems that more responses have overestimated than underestimated the age. This may be a result of judgements relative to their perceived incontrovertible oldest event.

Table 10.4 in Appendix 6 shows a comparison of all high school age data from AC and IS (13 years to 18 years). Multi-variate analysis by minimum variance cluster analysis (Kovach, 1998) of Year 12 data from Table 10.4 was then carried out to see if there were any meaningful statistical groupings of geological and fossil events. The resulting dendrogram is shown in Figure 10.12. It is not surprising that despite 53% of responses overestimate the scientific theory of plate tectonics as being more than a thousand years old in conceptual origin (including outliers), most students correctly isolate question 4 from others as the plate tectonic theory is mostly within an 'experiential' memory and encountered in various subject areas and in newspapers whenever there are earthquakes, tsunamis or volcanic eruptions. Plate tectonics is the dominant concept in geological and geoscience curricula. Question 4 also recorded the highest percentage of correct answers.



Clusters are:

A. Beginning of time, Big Bang, Milky Way galaxy, Formation of Sun, Formation of Earth, Formation of Moon, Formation of Earth's crust, First rocks on Earth.
B. Countries oldest rocks, First fish, Opening of the Atlantic, First volcanoes, First life forms, First dinosaurs, First trees, First organisms with hard parts, First land animals, First birds.
C. Development of plate tectonic theory.
D. Extinction of trilobites, woolly mammoths and large dinosaurs, The Ice Age, First humans.

Figure 10.12. Cluster dendrogram for AC Year 12 responses to Question 3.

Figure 10.12 shows a cluster analysis of Year 12 responses to Q3 section B (From Figure 10.11, Appendix 6) Cluster A, event 9 (Age for the formation of the Sun) seemed to provide the greatest difficulty, where no response was correct and 95% overestimated the time. It is as if the Sun is considered the oldest object around and so "must have a huge age that is completely separate from all other events" (student verbal response). Connecting events relative to each other appears to be a difficult task as responses seem to treat each event on the questionnaire as a separate issue.

Cluster B seems to show that students look for similarities in the words rather than the relativities of timings by lumping all the "firsts" together when they are widely separated in times. For example lumping the first life forms on Earth with the first fish and the first birds (but significantly, not the first humans), either indicates lack of knowledge of an evolutionary story or searching for anything in the given information that is similar or apparently relevant. Perhaps humans are too removed (and often not considered to be animal) to make it into this group.

Cluster C is clearly an isolated and obvious answer, although the boundary of 100 may be a little ambiguous for some respondents. Cluster D follows a similar path: where the common word is extinction. Hypothetically, because humans are perhaps conceptually seen to be too removed from all the other animals, the only sensible place they can be connected to is the Ice Age. These clusters seem to suggest that time ordering of geological and fossil events for these 16/17 year olds is more dependent on a prior knowledge base and search for similarities (classifying) rather than fixing timing within a relativistic framework. Future research with a much larger sample of this age group could investigate reasons why age estimates are overestimated almost twice as much as those events that are underestimated.

10.8 New Zealand AC Year 13 (17/18 year olds) Responses to GeoVAT

Year 13 students in NZ are in their final year of secondary school before entry to a university. These 39 students have had four and a half years of science training and all were enrolled in NCEA Level 3 achievement standards for Biology (See Chapter 9 for curriculum details). The average age was 17 years and 3 months.

Tables 10.4, 10.5, 10.7 and 10.8 in Appendix 6 compare NZ Year 13 student responses to ideas about fossils and other significant concepts of biological evolution, to older and younger students. Questions 9, 10, 11, 15, 16 and 18 stand out.

Across an age range of 16 to 22 years, results to question 9 indicate that the majority of AUB Primary trainees (74% in Table 10.7) Charles Darwin to have been the first to think of evolution (as an explanation for life's variations), whereas most of the New Zealand Year 13 students (mean of 62%) do not. Perhaps this primarily reflects differences in curricula and curricula delivery? If so, what? On average, 32% of the total NZ responses do not think that humans have evolved from apes whereas 42% of the UB students do. Question 11 results suggest that the UB sample and **A**C students are more secure in knowing the age of the oldest fossils on Earth but the UB and UC older students are not. Interestingly, an average of 30% of the NZ sample think that a scientific theory is just a guess but none of the UB sample thought this, suggesting a need for enhancement of teaching about the nature of Science and what a scientific theory really means. Indeed, as previously mentioned this is addressed in the NZ science curriculum and implemented in 2010. To what extent and how, are the key issues. Around 50% of the NZ samples appear to be unclear that all living things do share the same basic DNA coding system but that again, only 26% of the UB cohort thought this was correct. Perhaps there are interpretation difficulties with what is meant by "basic DNA coding system" (This means that all living things share the same base pairing rules for protein synthesis and so share common ancestry).

Around 62% of all responses do not consider new species to have appeared suddenly in the fossil record (punctuationism) although it is significant that the Year 13 AC cohort has the highest percentage that do. This aspect of speciation is taught directly but minimally in the NZ Year 13 Biology curriculum, and is examinable. Question 18 is notable for the significantly different response of the UB cohort, where 89% of responses consider the scientific method to be the control of variables.

Not surprisingly, when asked about supplying reasons for any two of their 'true' responses, the most common response was for question 7 (fossils are important and interesting) was because they tell us about the natural history of life and environments. It is curious that responses tend to link animals with fossils rather than plants. And one response stated, "Fossils are a sort of time machine". The following are a selection of other 'explanations'.

"God does not have anything to do with fossils."
"A scientific theory is a guess until it is proven."
"Earth was made in six days when the Big Bang happened –it was pretty quick".
"Fossils are the bones of once living things."
"Scientific method is checking hypothesis predictions against observations of reality to see how truthful they are."
"Yes, fossils are buried dead things but **not one** intermediate between changing species has been found; and red blood cells found in millions of year old dinosaurs – good one!" Where does this statement come from?
Statement 14 (See Table 10.5) also elicited typical strong creationist responses from two students.

1. *"The Earth was made in six days. For me it takes* ***more*** *faith to believe in a theory that life happened by random chance and all the intricacies of the human body than to believe in an all knowing and almighty God that designed everything. Saying that a building has no architect is foolish in the same way our beautiful Earth and organisms in the world must have a creator"*
2. *"Design is evident in the world – irreducible complexity. Therefore there must be a designer – God"*

The challenge for Biology teachers is to not only recognise and acknowledge pre-existing conceptualisations (and incorrect pseudoscientific perceptions) about evolution and the significance of the fossil record, but also to be able to present a scientific theory that is demonstrably trustworthy, valid, reliable and overwhelming in an effort to promote a conceptual crisis that actually shifts thinking. As Brem, Ranney and Schindel (2003) point out:

> *"Our concern is that if the complexity of evolutionary theory and its consequences is not appreciated by students, it may impair their ability to make informed, independent decisions, and resist dogmatic pressure from all sides. What options does this leave a Biology teacher?" (p.199)*

These responses reveal a range of conceptualisations about what these students considered were worthwhile writing an 'explanation' for. There is little argument about what fossils were, but there is some insecurity about how they were formed. There are also importantly, insecurities about the concept of punctuated equilibria, alluded to in question 16. NZ Year 13 students from the same institution as Year 12 students clearly benefit from tuition on rates of evolution in class where they recognise the importance of stasis and punctuation in the fossil record as a measure of rates of evolution. This is part of a Biology assessment standard. However this is in contrast to the idea of gradualism where on average, over 83% of all responses consider being the main feature of rate of evolution. How students conceptualise 'rate' in any science area is a rich field of future research. Statement 18 reveals tantalising conceptions about the nature of the scientific method, where stereotyped views of physical science methodology (Controlled hypothesis testing or 'fair testing') tends to dominate over the comparative and 'pattern' seeking approaches characteristic of the geological and biological (especially environmental and ecological studies) sciences. It is unclear why the UB primary school teacher trainees responded by overwhelmingly indicating that scientific methodology did not involve only the controlled testing of hypotheses, whereas all others did. Does this reflect differences in teacher training and curriculum delivery?

Question 3: Why are fossils found on tops of mountains? Year 13 Responses.

The following are typical explanatory responses provided for this question. Many reveal a typical search for answers in the information given either because of fear of ridicule, inability to express, laziness or genuine ignorance.

Typical explanatory responses include:

"The material was deposited on top [of the mountain]"

"Hasn't been there long – since the last flood"

"Tectonic plate movement"

"Sea level changes"

"May have already been there"

In summary:

(a) Found in place at the top = 31% of responses (n = 39)

(b) Don't know = 8%

(c) Pushed by earth forces = 51%

(d) Confused responses = 10%

Findings for **Section B Question 1 a:** Observable skeletal changes in a stratigraphic sequence indicate that most students were able to not only recognise a decrease in toe number but also specifically linked this to time. At this age then students are able to link structural evolution of fossil bones to geological time via recognition of a stratigraphic sequence where the oldest is identified as the bottom layer (no information was given about overturning or other tectonic change). Around 15% of responses (n = 39) indicated a specific link with an evolutionary change, and around 10% simply recognise a change in shape without linking to any process. Other reasons suggested for toe reduction included:

"*Toes were not needed so they evolved" and Layer 1 were smaller moved slower therefore less sturdier on feet"* (Lamarckism is a common misconception).

"Toes are turning into a leg bone".

"Change is caused by in-situ bacterial deformation"

"Was ground up and decayed in-situ"

Creationist response conceptions invoked the idea of *"…degeneration and loss of genetic information which results in* less *complex 'feet' with the "number of bones complexity of mechanism reducing it"*.

These responses suggest:

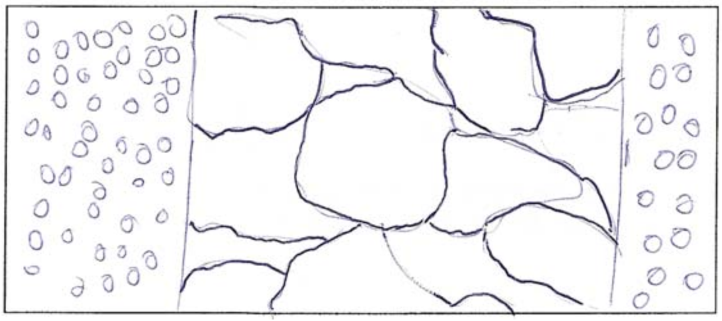
- That degeneration is a substitute for biological evolution by recognising change without having to say the E word. These students recognise skeletal changes but do not acknowledge them as evolutionary in origin.
- A lack of understanding of creationist rhetoric involving nonsensical and incorrect ideas of 'irreducible complexity' in an attempt to use (rather misuse) this terminology as a justification for non acceptance of biological evolution. In short, these students can not contextually use creationist pseudoscience propaganda as explanation for recognised change, when faced with fossil evidence as shown in the stratigraphic sequence.
- Fossil evidence is erroneously construed to be the remains of animals of "the same type" and therefore they have not evolved. This alludes to the idea of the meaningless biblical 'kind'. As Scott (2004) points out, 'progressive creationists' types or 'kinds' of organisms "are viewed as being genetically limited :as a result, one kind cannot change into another" (p. 62).

Fossils are shown as being absent from stratigraphic layer 4, and students are asked to supply possible reasons for this. Around 60% of responses indicated that the animal portrayed became extinct, 36% said that the animals had immigrated, 8% considered that the environmental conditions did not favour fossilisation and another 8% (3/39) considered the animal was unable to survive environmental change- implying extinction. Table 10.6 in Appendix 6 presents several other respondent reasons for explaining the absence of fossils from stratigraphic layer 4 and provides an interpretation of the geological concepts that are involved.

Evidence statements in Table 10.6 also suggest that there is considerable misconception of how fossils form and their relationship to the physical environment. Although responses suggest that fossils are correctly known for what they are, there is little scientific understanding of how they form. The connections between the animals (and plants and bacteria) and their ecology is missing.

Section B, Question 2a, Cross Section Examples for AC Year 13 Students

Figure 10.13 shows examples of Year 13 student responses to cross sections A.



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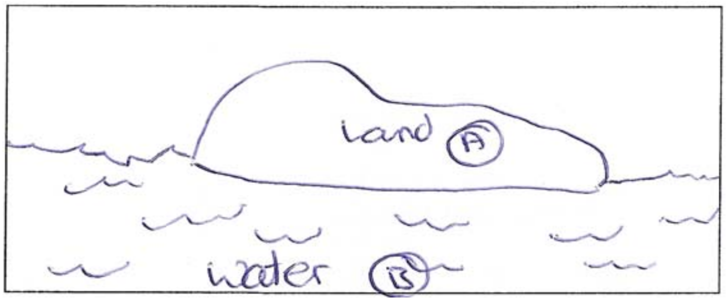

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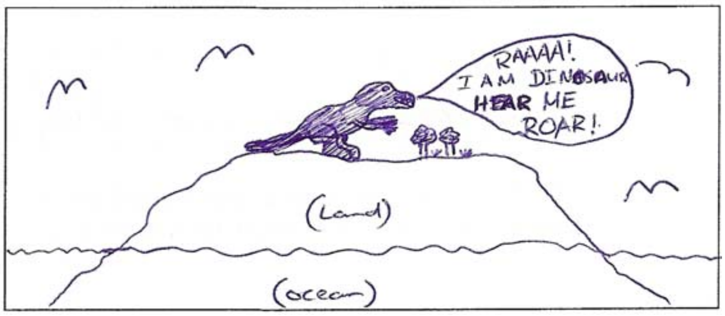

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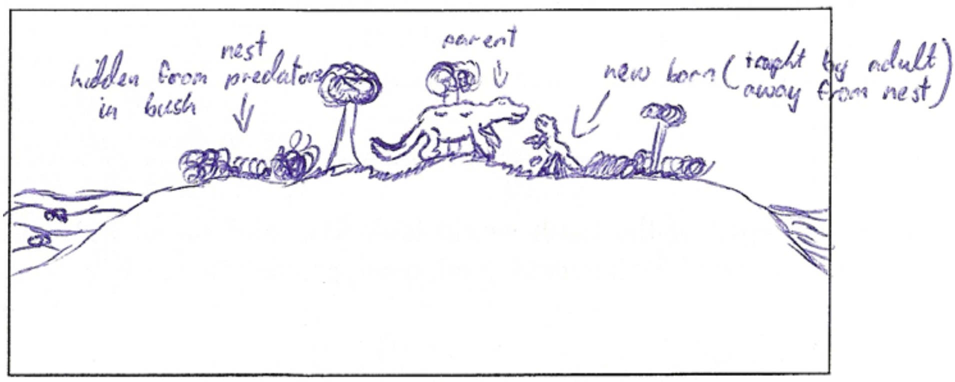


Figure 10.13. Typical Year 13 responses to Section B, question 2a of GeoVAT.

Q 2a Summary of Year 13 responses (Aged 17/18 years) (n = 39):

- Don't know = 23%
- Direct copy of given sketch = 10%
- Variation of given sketch = 5%
- Clearly incorrect = 12%
- Clearly correct cross section = 28%
- No response = 15%
- Indeterminate = 7%

10.8.1 Discussion: AC Year 13 Cross Sections

Overall, cross sections produced by these 17/18 year olds for **question 2a** display a similar conceptual pattern to all other age groups: there are those who can rotate 2-D into a slice, those who try, those who cannot and those who do not try. The scans shown in Figure 10.10 have been selected to illustrate a perceived general trend in sophistication from "I don't know" to an increasing amount of detail. Cross section A suggests that this student is unable to rotate a plan view but attempts to 'redraw' what is already given This is analogous to students attempting to reword given information in a written theory question or those who attempt to copy patterns from a 3-D geological structure (Chapters 7 and 8 and GeoTSAT). Cross section B reveals a typical compromise 'floating land' response where elements of both 2-D and an incorrect cross section are drawn. These students are unable to think and 'penetrate' downwards and have difficulty with boundaries. The water (B) and land (A) are directly derived from the given plan view. Diagrams C and D indicate a higher level of understanding of what a cross section is and typically show the dilemma students have as to what to do with the sea level water line: does it go right across (C) or is it ignored (D)? Cross section D adds in more detail derived from given information despite already having answered the question. Although 'drawing literacy' may be a limitation akin to 'narrative literacy' for expression of conceptualisation, both C and D clearly show these students are able to rotationally translate plan view into cross sectional view. This ability has implications for visual penetration ability of geological structures.

Question 2c seeks to find out conceptualisation of an alternating sequence of marine and terrestrial environments. Examples of explanations are shown below.

- Did not do = 33%
- Repeated floods = 10%
- Changing sea levels = 36%
- Movement of tectonic plates (universal cause = 8%
- Variable remainder = 13%

Other responses include:
"Area must be where the water rises to in high tide in summer"
Shows climate change"
"Water must have been rough to have no fossils"

Question 2d Summary of Perceptions of the Earth
First Formed: Hot, cold, barren, brown and quiet.
Today: Crowded, green and industrial. Busy, loud and noisy.
Responses here mimic other age group responses: in essence, it is the presence of humans that is different.

10.9 Summary for Ashburton College (AC) Year 13 Responses to Question 3

Question 3 results are shown in Figure 10.14 in Appendix 6. Estimations of relative time events are similar to the Year 12 cohort. Surprisingly, 91% thought that development of the plate tectonic theory was > 100 years old – a gross overestimation.

As indicated by the spread of responses Q1, (First appearance of fish), caused a problem but it is significant in the sense that students underestimated the first appearance time as perhaps suggesting an ignorance of the old age for this event and an inability to place this event in a time-relative position. Similarly, responses to Q18 suggest that these students have an immature (Relative to accepted scientific ages), idea of the much older age for the first appearance of modern people than they think. Perhaps this is related to perceptions of what 'human' actually means? But either way, it is difficult to reconcile with their Year 12 counterparts where 47%

underestimated the age as opposed to 91% of Year 13 students from the same institution. Extinction of dinosaurs and the first appearance of the birds were also significantly underestimated in age. The age for the Big Bang and the formation of the Sun (And implicitly the solar system), were both grossly overestimated in age in a similar way to all other age groups as if they are recognised and perceived as the oldest in age so therefore must fit the oldest 'J' category without relating the age categories to one another. This supports Trend's (2001) data where primary school trainees' (two years in advance of this AC Year 13 cohort), fundamental, 'large scale' time divisions are recognised, but were lumped together and overestimated. Exactly why this occurs is open to future investigation. T-test analysis indicates no significant difference in event-time estimations when comparing the Year 12 and Year 13 overall means for a correct relative age orders (see Appendix 5 for GeoVAT questions).

Results are also similar for all other age groups suggesting that there is little conceptual and perceptual change taking place over an age gap of ten years. However, as Trend (2003) pointed out, results may say more about student perceptions rather than their conceptions. The relationship between perceptions and conceptions of deep time is a future area of 'fruitful' research. For example, to what extent do students use cues in the events, and what are the key reference points for assigning relative ages when unknown? Results for all age groups (with a gap of 9 years) also support Trend's results that 'Deep Time' events are perceived in broad categories rather than the scientific refined relativity. Limitations of '*internal feedback relationships'* of each event may significantly influence results as well as individual knowledge base, world views and cognitive status.

Unless specific geological training is undergone, this conceptual status is likely to remain probably for life. The challenge for educators is to address this static conceptual (and perceptual) status. As Orion and Ault (2007) imply, research efforts should "provide an understanding of student's difficulties with learning processes" identify appropriate and relevant teaching strategies and develop "cognitive capacity for systems thinking" (p.67), Commonly and unfortunately, without adequate pre-service and in-service training, resourcing and funding which enables the development of integrated reductionist and holistic values, this goal is likely to be unattainable and the unique properties of Earth Systems Science and the underpinning principles of geological science will continue to be lost. Although easy to state but more difficult to evaluate, Ault (1998) aptly pointed out:

> *The role of the curriculum comes to an end once the learner achieves independence in accessing, using, and evaluating knowledge according to the relevant criteria of excellence. (p. 211).*

10.10 New Zealand Year 9 (13/14 year olds) Responses to GeoVAT

This typical cohort of Year 9 students (first year of secondary school in NZ), had an average age of 14 years and 7 months and the questionnaire was completed half way through the year. Minimal tuition in Earth Science or Geology had been given to these students and the results are expressed as percentages of the responses and then compared to other cohorts. Table 10.7 records the response distribution for AC Year 9 students compared to other cohorts for responses to question 1 of GeoVAT.

When one considers the age range (13 to 22+ years), and students from different countries, it is remarkable that even for this very small sample the results for each question are in nearly all cases insignificantly different. The UB primary school teacher trainees are different in questions 9, 10, 11, 15, 16 and 18 but all other results by ANOVA are statistically indifferent (F = 19.7. p = 0.01. F crit. = 2.3). It seems that the AC Year 9 have similar responses except that unsurprisingly, 79% of responses consider Charles Darwin to be the first to think of evolution as a mechanism for life’s diversity. This is similar to the UB responses but different to all others. This is unsurprising because the responses reflect the fact that Charles Darwin is known but these students have not been exposed to any teaching about biological evolution. They simply associate Darwin with evolution and little knowledge of the historical development of the theory. Question 16 is also similar to UB results. Year 9 AC students consider the rate of evolution to be gradual and they have no knowledge of punctuationism like their elder students from the same institution.

Reasons given for Year 9 statements considered to be true include:

- Fossils are important and interesting (statement 7) because they "tell us about the past" (11 responses); that "scientific theories must be true and not guessed at because this would be a waste of time" (2 responses); "we look like chimps so we must have evolved from apes". A common response from all age groups is to not actually supply a reason, but merely supply a statement of perceived fact. Students do not know why they know things - they just know. Typically, reasons for finding fossils at the tops of mountains is that the flood idea is correct and that animals just died up there. Rarely do students of Year 9 age consider that mountains are raised from the sea floor to be 8Km above sea level!

Other reasons include:

- The Earth was made in six days because "my religion tells me this" and "all through my primary school that was what we were taught in religious studies" and "God sent down the rains and made the great flood, things drowned and floated on the water and they got left at the top of the mountain". The power of religious dogma is very clear for some students and is a concept at that time, perhaps more acceptable than a scientific theory, especially when the nature of science is not understood and despite enshrinement in the NZ national science curriculum of 2007 (Chapter 9).

Although significantly independent, **question 1.a. section B** (Appendix 5) responses are also similar to all other groups. The changes are generally recognised but the reasons are often confused. For example, "bone gets corroded away over time" or "the bones deteriorate". Most responses indicate a connection with geological time as shown by the rock layers. This supports the early work of Ault (1981) where young children are able to connect time with rock strata in terms of superposition, and Montangero's work (1996) where young children are able to detect diachronic changes in observable physical transformations. Conceptual explanations are a different matter.

Section B question 1b asks for explanations for absence of fossils in upper rock strata. This is what these students typically say.

"Things making fossils became extinct"

"The ground rose up"

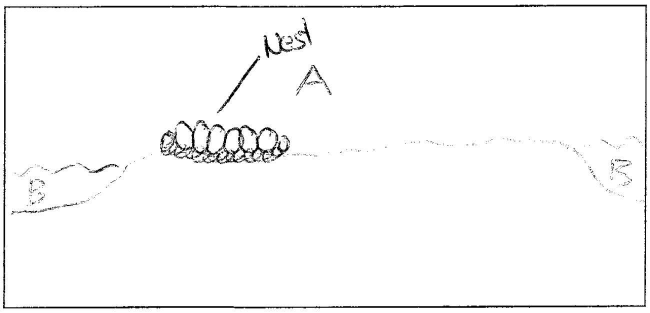
"The creature died out or stopped growing"

"Lack of oxygen below the surface"

These responses suggest that there is little connection with environment in a biological sense and a poor understanding of spatial/geographic/ecologic relationships associated with organismal distributions.

Question 2a asks students to display their understandings of spatial rotation from a map plan view to a cross sectional view. Typical responses are shown in Figure 10.15.

A



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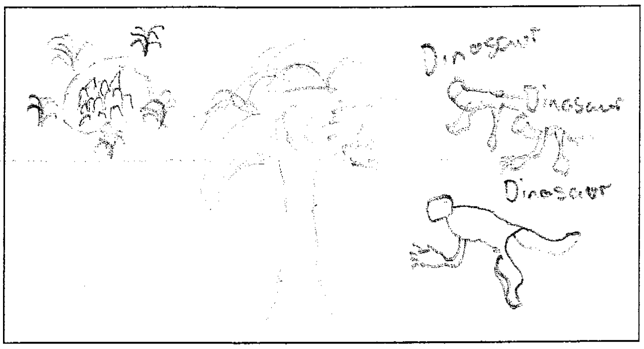
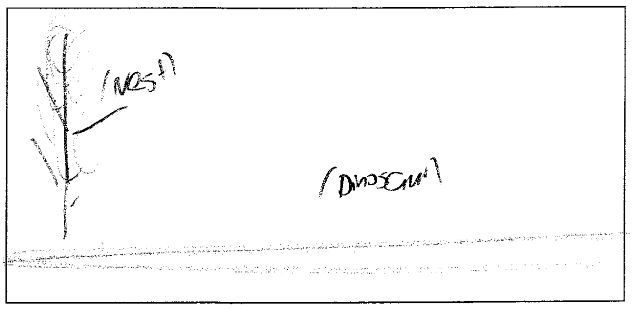


C



D

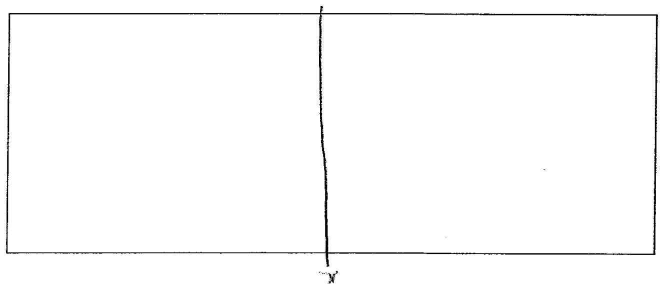


Figure 10.15. Typical Year 9 responses to question 2a of GeoVAT.

These responses suggest similar conceptual thinking to all other age groups where there is a range from “don’t know” to copying the plan view to partial cross section. Scan E is interesting because this student seemed to know what a cross section meant but had no idea how to translate the plan and ended up copying the given X-Y line vertically. Students constantly look for answers in given information when they are insecure. The older students were generally more sophisticated but still retained juvenile elements. If students of 14 years old struggle to spatially visualise cross sections and are generally unable to translate plan view to cross section, this is likely to have significant effects on general subject learning.

Question 2b only elicited one response. “Was the dinosaurs territory and they had families”. This indicates that some students of this age are able to identify and connect fossil remains with life processes. Question 2c typical responses include:

“Dinosaurs died in certain seasons”
“Every second summer the area was flooded”
“Used to be a lake or river which dried up and land animals lived after fish died out”

“Would flood every now and again and dinosaurs were wipe out. Some survived and then died and their fossils were in the land. This was a continuing pattern”

These responses suggest that students of age 14 years in this small sample were able to make diachronic linkages with seasonal change as recorded in rock strata (geological time), and with changes in stratal position of fossil preservations.

Question 2d responses are summarised below.

First Formed	**Today**
Brown, small and hot	Green (5 responses) and bigger
Quiet (8 responses)	Loud (6 responses)
Volcanic	Cities and cars

Section B Question 3 elicits a student conceptual status for the nature of fossils and perceptions and conceptions of bio/geological events through time. The results for Year 9 students are compared to other groups from the same institution in Figure 10.16, Appendix 6. It is rremarkable that the mean overall relative time/event distributions are so similar given the independent completion times and age differences which in effect spans the secondary school years. Conceptual status of relative placements of diachronic events appears to be much the same for each group and there is a consistency for overestimating times especially for questions 3, 24 and 23. Placing what are considered the oldest events are simply connected to the oldest age category without comparing the age relativities in the ranges. In short it seems that students of all ages make judgements based on the events themselves rather than using the given age categories as the relativity benchmark. Perhaps the reference point for all events is compared with what the individual perceives to be incontrovertible. It is interesting that the age for the formation of the Moon and the first appearance of the birds gained the most correct answers. Overestimation of event timing is common. Although these results are gathered from a small sample it is remarkable that the means show no significant difference despite being from across different age groups and independently completed (Table 10.13).

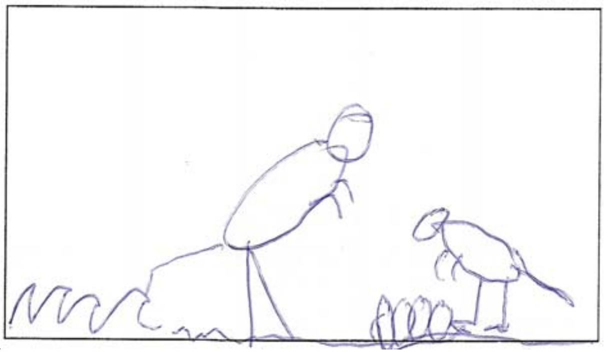
10.11 New Zealand Year 11 (15/16 year olds) Responses to GeoVAT

This cohort of 25 students has an average age of 15 years and 4 months and represents (not statistically) an anecdotally typical 15 year old conceptual status. the Response distributions for question 1 section A compared to other cohorts is shown in Table 10.6 in Appendix 6.

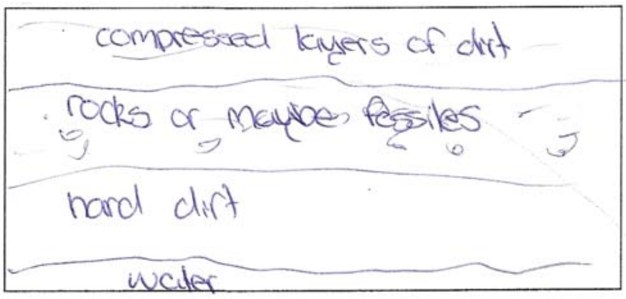
The overall results for Year 11 students are remarkably similar to all other cohorts with the exception of question 16 – punctuationism. The concept of punctuationism is not encountered in NZ schools until their final year and then only if students study Biology, so it is hard to explain why the Year 11 results are similar to Year 13 results for this question. Gradualism is encountered in general knowledge and some science and this may help explain the contrast in cohort results. Again, the dominant concept displayed by this Year 11 cohort of science methodology is ‘controlled testing’.

Question 2 elicited the general consensus that fossils “show us animals [not plants] from hundreds of years ago” and that fossils are just accidents because they happen”.
Typical ‘explanations’ for question 3 include:
“They were up there when they died”
“They got washed up there”
“Stuff above gets washed away so gets uncovered”

Question 2a Section B which asks students to show how they spatially think again displayed commonalities’ with all other groups. Example A (Figure 10.17) is an interesting attempt to translate plan view into cross sectional view. It shows a mixed conceptual and perceptual state where elements of cross sectional view are conceived and perceived, but also an inability to draw the cross sectional relationship between the island and the sea. In the examples A and B below, there are clear elements of ‘copying’ the given diagram but also a cross sectional view.



A



B

Figure 10.17. Typical Year 11 responses to question 2a Section B – cross sections.

These examples for Year 11, along with all other age groups, consistently demonstrate how respondents look for clues in the question and when not found attempt to 'rewrite' the given material with their own spin. Thinking below the surface in a cross sectional way presents challenges for this age group. Students of this age were clearly able to make the connection between fossil evidence and the idea that this evidence indicates life histories within a diachronic framework.

Question 2c provided too few returns for comment, but **Section B question 3** results are shown in Figure 10.18, Appendix 6.

The mean results indicate no significant difference in diachronic event categorisation to all other age groups, strongly supporting the findings of others (Dodick, 2000b; 2003a; Downey, 1994; Trend, 1998, 2000a, 2001a; 2001), that many early formed concepts are held onto tightly and simply modified or ignored until there is sufficient dissatisfaction and cognitive ability to accommodate change. It is typical that even for event 4 which recorded the highest percentage being correct, (Development of plate tectonic theory) that this event is over estimated, with most ever estimates indicating a time of between 100 and 1000 years. Development of concepts since the late 1950's is perhaps still well beyond the perceptual reach for teenagers (Figure

10.17, Appendix 6), where only 33% were correct. It is unlikely that any student actually knew the answer, and indeed, the vast majority of all results failed to elicit an attempt at an actual age. This appears to be just too difficult (or time consuming) to respond to. Just like other age groups, the beginning of time and the formation of the Milky Way galaxy events are considered to be synonymous with the oldest age category. This again suggests that responses are not derived from consideration of relative comparisons of provided time categories but by reference to a perceived correct answer. Anything older than the oldest perceived age is ancient and is therefore lumped into the oldest perceived category. 'Lumping' of categories rather than 'splitting' is the most common approach (Trend, 1998, 2000b; 2001). That 93% of responses underestimate the correct age for human origins suggest difficulties for definition of 'human' especially when this cohort has virtually no knowledge of the scientific view of human evolution. This cohort also like most other cohorts clearly and unfortunately had no idea of the age of the oldest rocks in New Zealand. Do you? (For NZ, about 540 million years ago: but only the last 12% of Earth's history)!

10.12 Israeli (IS) Student Responses to GeoVAT

A small but tantalising sample from Israeli students provides an interesting and useful comparison of responses to the conceptual status of ideas about evolution and geological time for high school aged students. These students aged 15 and 18 years and nurtured in a Middle Eastern culture but taught universal geological concepts and contexts provide a measure of 'internal triangulation' and comparison. Unfortunately, because responses are written in Hebrew and not translated, only results to Section A question 1 and Section B question 2a and 3 were able to be recorded. I would speculate that responses to other questions would be similar to other cohorts.

Findings

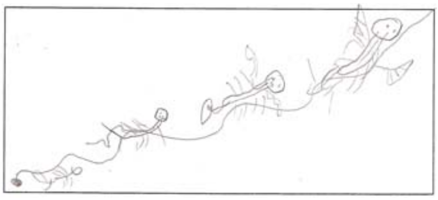
Results to Section A question 1 (true/false responses to ideas about fossils and geological events), are similar to all other high school age cohorts (Table 10.4, Appendix 6) but with specific question differences. These are highlighted in blue. T-test analysis indicates that there is no statistical difference between the two year groups for IS samples. Across all cohorts however, sample sizes are too small to make any other generalisations.

Although decreasing with age, it is interesting that the older AC Year 12 and 13 cohorts **do not** consider Charles Darwin to be the originator of the idea of evolution but the IS Year 12 and 13 age groups do. Does this reflect differences in Biology and science curricula, teaching and cultural values? About 40% of the IS Year 12 responses indicate that science is *"just a guess"* but at Year 13 (Grade 12) this idea is reversed. When the AC Year 13 group is compared to the IS Year 13, 31% think it true that a scientific theory is just a guess but the IS Year 13 group had 62% thinking this. Why? Were students confused by the question? Or did this cohort really think that a scientific theory **is** just a guess? Across all age groups, on average, 20% (N = 77) thought that the Earth was made in 6 days. The IS Year 12 students were the least sure at 50% on this! Oh to have 300 samples! On average 59% of **all** responses think that 'the' scientific method is only the controlled 'fair' testing of hypotheses. The IS Year 13's show the lowest percentage that (correctly), that this is not so. Teaching the nature of 'scientific investigations' beyond controlled experiments is a challenge for science teachers in developing an appreciation (as well as implementation) that pattern seeking and comparative methods are also often used are scientifically valid but take longer at school to complete.

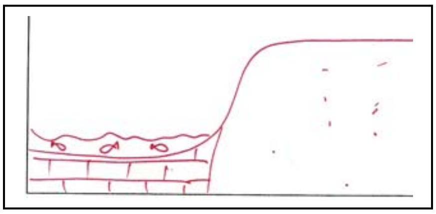
Question 2a Section A looks at the ability to translate plan view into cross sectional view and requires the visual/spatial ability to rotate as well as to place unseen information (eg hidden rock strata and their boundaries) into correct positions (Visual penetration ability). Figure 10.19 represents scans of a range of responses from no cross-sectional perception to acceptable cross sections.

IS Grade 11 (=NZ Year 12, age 16/17) Selected Cross Section Responses

IS Grade 11 (A)



IS Grade 11 (B)



IS Grade 11 (C)

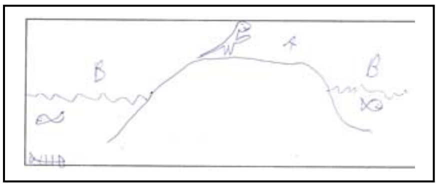
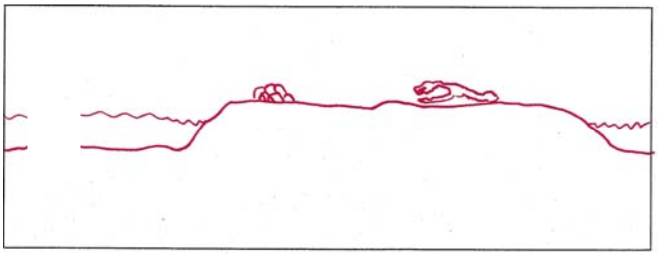


Figure 10.19. Typical IS Grade 11 responses to Section B question 2a.

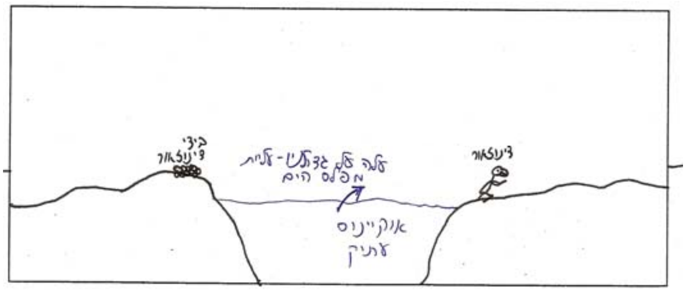
Scan A for IS Grade 11 (Figure 10.19) appears to be a modified copy of the given information (Appendix 5) where the dinosaur is simply copied along a diagonal line. This is typical of students who have little idea of what a cross section is and so are forced to copy what is already there but drawn differently to indicate that an attempt has been made on the question. Scan B shows an interpretation where only half of the 'island' is shown but with the rare addition of rock material making up the sea floor. Scan C shows the most typical of accepted cross sections with a disconnected 'bottom' or sea floor.

IS Grade 12 (=NZ Year 13, age 17/18) Selected Responses

Grade 12 (A)



Grade 12 (B)



Grade 12 (C)

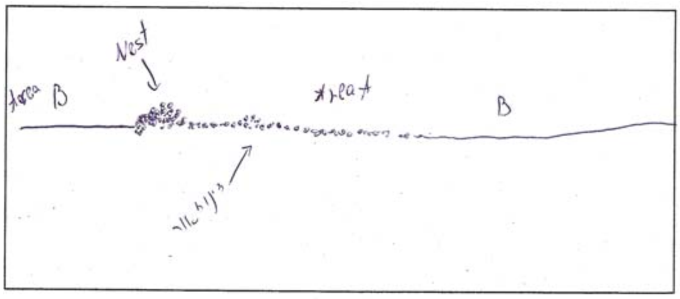


Figure 10.20 Typical IS Grade 12 responses (NZ Year 13) to Section B question 2a.

The IS Grade 12 scans (Figure 10.20) show a similar range of responses; from acceptable (Scan A) to the ‘inverse’ of the given diagram (Scan B) and a minimalist approach (Scan C). In common with responses across all cohorts, pictures of the dinosaur skeleton and nest area are simply copied in. All responses for the IS Year 13 cohort showed cross sections indicating little difficulty in rotating the plan view to the cross sectional but it is common for responses to 'invert' the land area above sea level to one below sea level as in Scan B. Perhaps students perceive the 'white' island area (See Appendix 5) as a depression rather than an elevation. They also often fail to connect the *word* information with the *picture* information.

Figures 10.21 and 10.22 in Appendix 6 show the distribution of results for the time related events for Question 3, Section B. In summary, the Grade 11 students overestimate the times for each event more than the Grade 12 students but both cohorts are similar in their percentage of correct answers. It is surprising that 44% of Grade 12 and 63% of Grade 11 students did not know the so recent advent of plate tectonic theory. Like all other cohorts, the 'beginning of time' is commonly accorded (incorrectly) the oldest time category of J (more than a million million years old). Also, like other cohorts, very few know the age of the oldest rocks in their own country. This is likely to be true of the whole population because geological science and how rocks are scientifically dated is rarely taught.

10.13 New Zealand First Year University Geology Students (UC 1) Responses to GeoVAT

Summary of Results

In common with all other cohorts, these students considered fossils to be important and interesting because they tell us about the history of life. Responses are typically knowledge-based statements rather than conceptual explanations using scientific evidence. This is a common written examination answer problem.

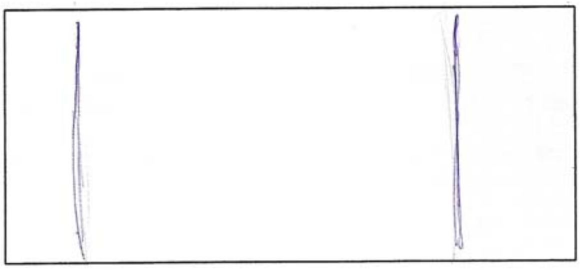
The vast majority of responses correctly understand the need for uplift when explaining why fossils can be found at the tops of mountains. In so doing this implies an understanding that fossils were moved from the sea floor to altitude. Nevertheless, a small number (3/28) considered that the organisms died in place on top of the mountain, 4 responses were totally confused, one was a 'saboteur' and another considered that the draining away of a great flood was correct. It is surprising that 30% of these first year geology students did not consider uplift to be a factor.

Again, although the majority of responses are correct in identifying changes in fossil bones only 16/28 responses (57%) were linked to a diachronic basis. That is, most students observed skeletal changes but they did not link these changes with rock strata through time.

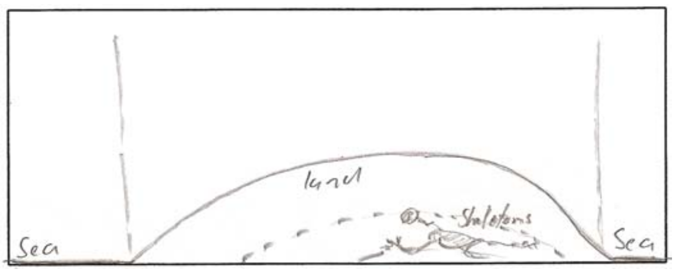
Most considered the absence of fossils to be caused by extinction or migration (68%) with the remainder linking fossil absence with environmental change. None linked migration with environmental change they just think the animals just disappeared. Some responses suggested that "the bones disappeared from breaking down" and "fossils could be eroded away and soil took their place", suggesting significant conceptual difficulties in explanation. In essence this cohort considered the early earth to be hot, volcanic and loud and today, green, loud and "man made".

Figure 10.23 shows representative scans of cross sections by UC first year students for Section B question 2a (See Appendix 5 for the questionnaire).

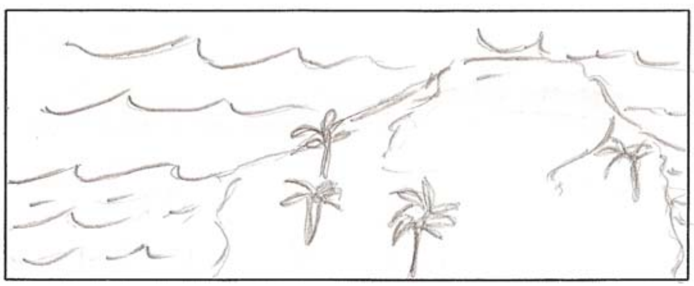
A



B



C



D

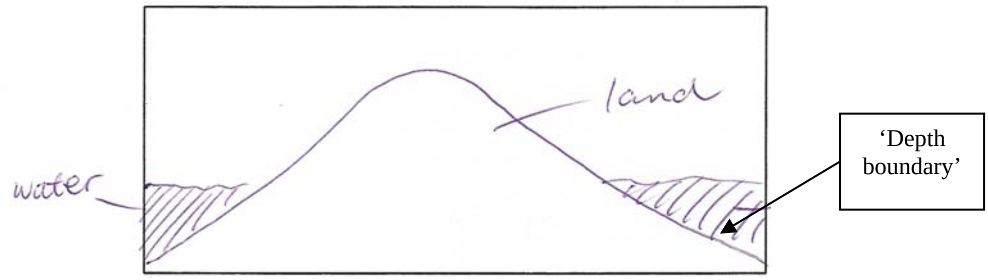


Figure 10.23. Typical UC first year geology student cross sections.

Similar to other cohorts, these first year geology students (half way through their first year) show a range of responses from inability to rotate plan view to the hidden cross sectional view (A,B and C) to a complete cross section (D). The ability to position 'hidden depth boundaries' directly influences spatial reasoning and visual penetration for geological structures in 3-D (See Chapters 7 and 8).

10.14 New Zealand Second Year Geology Student (UC2) Responses to GeoVAT

Summary of Results

This cohort results for question one of the GeoVAT questionnaire are summarised in Table 10.12. In essence, there is little difference in undergraduate and postgraduate understandings of what fossils are and concepts surrounding them. It does seem (thankfully) that postgraduates do have a more sophisticated view of the rate of evolutionary change as expressed by the concepts of punctuationism and gradualism.

This cohort of second year geology students has a mean age of 22 years and 6 months. Explanations offered in response to **question 2** ranges from *"No one knows the absolute truth apart from God –all we can do is guess"*, to *"Can't think of explanations – just know the facts"*. This last response exemplifies the difficulties students have with providing explanations– even at second year university level, and there is a tendency to just make statements or reword the question rather than provide an explanation.

Most responses for **question 3** invoke plate tectonic uplift as a cause but one even agreed with the question! Another confused response was: *"You mean that the world was originally flat but due to the older heavier oceanic crust and the sped up plate tectonics, fossils that were deposited on the originally low sea floor were pushed up much faster than currently because the older heavier plate has been subducted almost fully except as small part of plate left subducting beneath the Andes in S. America"*. A little knowledge is a conceptually dangerous thing!

All responses for foot bone changes were correct except the confused and pseudoscientific creationist viewpoint: *"It is very likely that only a piece of each of the bones have been found and altered to appear as changing or evolving –which will later be proven to be a hoax like so many have. Changes within species do occur but only as a result of a loss of genetic information, not the development of new information"*. What can one say? Reasons for the absence of fossils include a correct understanding of unconformities, extinction, lack of preservation, migration and unsuitable environments.

Question 2a has only so many possible responses. Figure 10.24 shows some of these responses. Scan A appears to be a sort of mirror image where land is kept in the same position but the sea is extended upwards instead of downwards as if the student did not know where to place the sea/land boundary in a vertical section. Scan B is unusual in that although a cross section s attempted, the sea / land boundary again was unknown. Scan C is a correct response with clear understanding boundaries and the need to have the sea shore in correct positions relative to the plan view. In keeping with most responses, a picture of a dinosaur appears to be necessary to keep a connection with given information. This response also recognised that sediment forms on the sea floor from erosion of the land. And, these responses are from second year university geology students going on 23 years old.

A

B

C

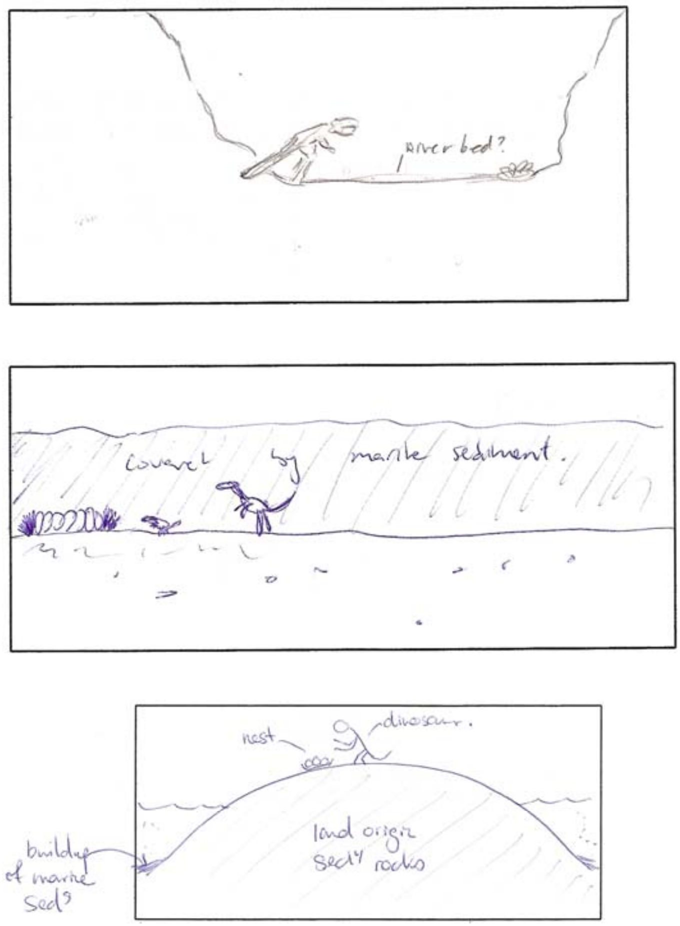


Figure 10.24. Typical UC second year geology student – cross sections.

All responses were correct for connecting life with the past except a creationist who implied that fossilisation could not occur in a kind of denial of the fossil record. All responses correctly invoked an environmental interpretation using geological knowledge. The Earth when first formed was considered by this cohort to be originally hot and loud and today, green and loud. Second year UC responses to Section B, question 3 are shown in Figure 10.25 in Appendix 6 and described in the combined responses in section 10.15 below.

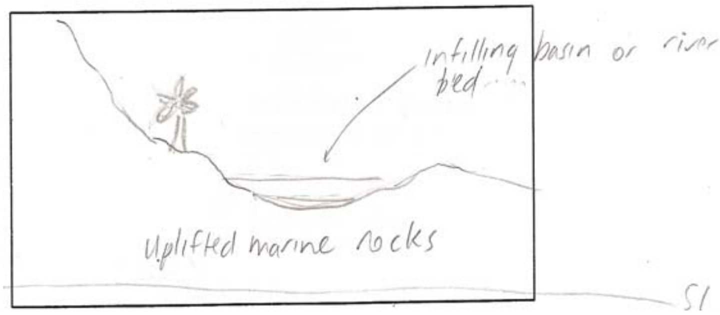
10.15 New Zealand Geology Postgraduate Responses to GeoVAT

Summary of Results

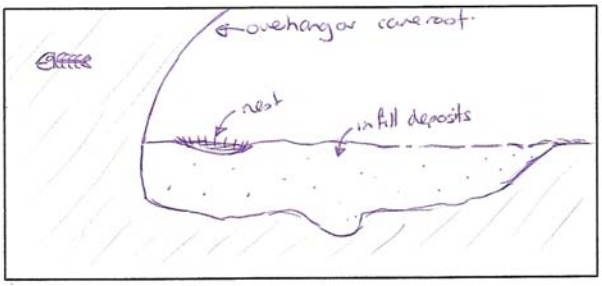
This small cohort (n =10) with a mean age of 26 years and 6 months display a modern view of what fossils are and all understand why the fossil record is important. However, 40% considered Charles Darwin to be the first to think of evolution and only 1/10 thought that humans have evolved from ape like ancestors. Even postgraduates have difficulty expressing what is meant by ‘human’ and seem to have a naïve view of the meaning of common ancestry. Humans are still considered to be “not apes”. Interestingly, 30% considered a scientific theory to be just a guess, and 30% considered that scientific methodology was only the controlled testing of hypotheses. This suggests a poor background in the understanding of the nature of science. Most responses, (90%), considered punctuationism to be false and that speciation occurred gradually. Twenty percent did not realise the universality of DNA base pair coding. Thankfully, none considered the Earth to have been made in 6 days and 70% knew that birds share a common ancestry with the dinosaurs.

Nearly all responses indicated that fossils were important for unravelling the evolution of life. One response to question 18 (Science methodology) stated *“Science puts forward a theory for what might happen. Science can only prove something is not true. If there is no evidence against the theory then it is the best idea on the subject”*. Comprehension by some postgraduates of the nature of science still requires more development. Tectonic uplift is the preferred reason for fossils being found on the tops of mountains and most responses implied an understanding that fossils were once living organisms on the sea floor. All responses correctly interpreted the fossil bone changes. The preferred explanation for absence of fossils was species extinction followed by habitat change, lack of preservation and erosion.
Even postgraduate geology students produce similar responses to visualising and rotating plan view into a cross sectional view for question 2a. Figure 10.26 shows selected responses. Despite the fact that these responses are from postgraduate students, there are still elements of confusion shown by mirror image inversion (A & B) and with C, an inability to rotate. Scan D shows the typical correct response with boundaries in position.

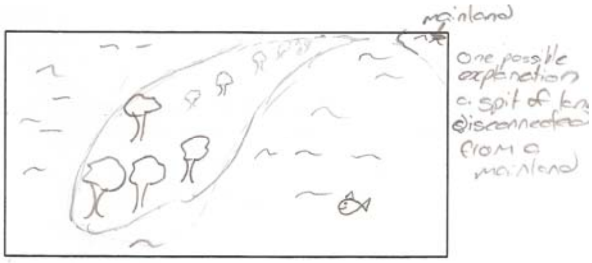
A



B



C



D

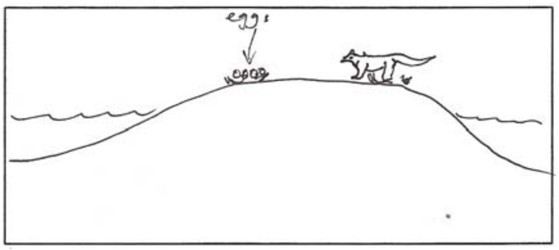


Figure 10.26. Typical post graduate geology responses to question 2a - cross sections.

The interpretation of the scenario for question 2 includes explanations related to environment and habitat with recognition of a living community where populations are breeding. Question 2c responses were dominated by statements like “variations in sea level” but there was little connection with the detailed information given. Perhaps questionnaire fatigue had set in?

This cohort of postgraduates considered the Earth to be hot, volcanic and loud when first formed but blue, green and loud today (acknowledging the role of people?).

10.16 Comparison of UC Secondary Teacher Trainee and AUB Primary School Teacher Trainees Responses for GeoVAT Question 3

Figures 10.6 and 10.8 in Appendix 6 indicate the spread of responses for Section B question 3: relative geological and biological events in the earth's history. Students are aged from 20 to 30 years old. As for other cohorts, these responses are expressed as under and over estimations of relative time events as well as those responses which are correct. All cohort responses to question 3 in the GeoVAT instrument were then compared in Table 10.13.

10.17 Summary of Cohort Means GeoVAT Section B, Question 3

Table 10.11 and Figure 10.27 summarise the results for student estimation of times for question 3: fossils and relative time events. Across an age range of 13 years, on average, 30% of combined cohort responses indicate an ability to correctly determine the relative times of known geological and fossil events.

About 30% also under **and** over estimate relative time as represented by the GeoVAT question 3 events in Appendix 5. The small cohort of postgraduate geology students provides a measure of benchmarking but even here, 20% on average are surprisingly still unable to make correct relative 'time-event' or diachronic choices. Evidence also indicates (gratifyingly), that as age and experiences increase, the degree of both over and under estimation of relative time events decreases and that the amount of overestimation decreases more than the amount of underestimation.

Table 10.11 **Summary of Means** for question 3 GeoVAT (Age 13 to postgraduate).

Cohort	**% Over estimate**	**% Under estimate**	**% Correct**
NZ AC Year 9 (n=13)	57	33	10
NZAC Year 11 (n=25)	44	38	14
NZAC Year 12 (n=13)	52	29	18
IS Grade 11 (NZ Year 12) (n=9)	42	33	24
IS Grade 12 (NZ Year 13) (n=10)	27	45	28
NZ AC Year 13 (n=39)	41	38	14
AUB Primary Trainees(age 20+) (n=14)	43	43	13
UC First year Geology students (age 19+) (n= 28)	29	31	40
UC Second year Geology students (age 21) (n=10)	20	38	43
UC Sec Trainees (age 24) (n=9)	34	26	42
UC Postgraduate Geology students (age 27) (n=10)	25	19	80
Combined Cohort Means (N = 160)	**38**	**34**	**30**

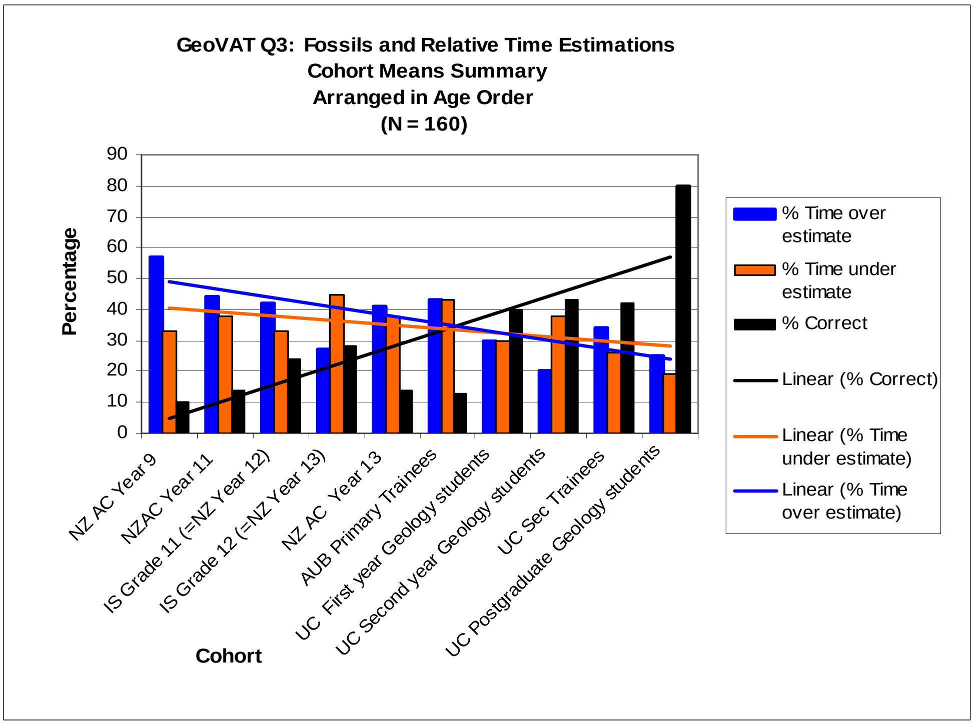


Figure 10.27. Cohort means analysis for GeoVAT question 3: time estimations.

The psychological phenomenon of *'forward telescoping'* of relative diachronic events where 'distant' events are perceived as being more recent than they actually are is supported by the data in this study where a lessened decreasing of *under estimation* of events as age increases is shown. However, postgraduate geology students (older and with more geological training), have a lessened percentage of underestimation of events, and the gratifyingly highest percentage of correct estimations of events. There is much room for testing the ‘scale’ of ‘forward telescoping’ (or underestimation) when applied to estimations of many other dimensions such as speed, distance, mass, temperature, mineral hardness and even depth of groundwater bores as shown by Dickerson, Callahan, Sickle and Hay (2005). Research by Catley and Novick (2009) suggests that there is no difference in the time related estimations of biological events between College/University age students who have and do not have biological backgrounds. However, they also report that there was a greater variation within the weaker Biology background students and that both groups were significantly inaccurate in their estimations. This study supports these findings. However, Catley and Novick (2009) also clearly point out the essential links between macro-evolutionary processes (the forgotten, defocused and misunderstood link, at the expense of micro-evolutionary processes), and geological time. Indeed, I would speculate that academic training in the biological sciences (Chapter 9) tends to encourage and focus on the genetically oriented micro processes before any discussion and linkage of macro evolutionary linkages with paleontology and ‘Deep Time’.

Conceptualising ‘Deep Time’ is a significant scalar learning problem similar to the difficulties involved in cognitively perceiving the size of atoms or the universe, or the mass of a whale compared to a bacterium, or the volume of an object (See chapter 5). Indeed, there is much to learn about the complexity of visual imaging and perception development of scale. As Gail-Jones, Taylor and Broadwell (2009) point out, even less is known about how visually impaired individuals develop their perceptions of scale and it is *how* these individuals develop their scalar senses that provides clues to understanding how sighted individuals develop theirs. The real challenge for teachers is to find efficient ways of enabling students to develop an appreciation of and perception of scales of dimensions to make better sense of geological history (local and global) and the evolution of life. In Hildago, Fernando and Otero’s work (2004) the issue of comprehension of time interval versus the nominal scale is raised. In other words, students may accurately estimate a time but do not comprehend what the **interval** of time represents. This is akin to being able to read the words in a text but unable to comprehend what they mean. Comprehension is all. So, when students are confronted with the geological time scale they can read the numbers but struggle to comprehend not only the interval between events but also its linkage with macro evolutionary events.

Teaching for geological time and its relationship to the evolution of life and geological events is a significant challenge (conceptually and contextually) for teachers and an even bigger challenge for curriculum developers and teacher training organisations. Implicit, is that to better comprehend the importance of evolution there has to be the building of more effective connections between the various sciences, diachronic thinking abilities of students, fieldwork, argumentation, mathematics, data processing and representation and individual world views. Specifically strengthening the links between ecology and evolution (especially paleoecology) would also enable a more sophisticated and connected understanding of evolution. Development of meaningful resources to aid development of perceptions of scales of time is a significant challenge yet to be addressed pedagogically as well as within curricula. However, we forget how immature our teenagers (and undergraduates) are, and how technologically and administratively immature schools are (that is, a schools technological computer hardware usually lags well behind the software), so finding appropriate manageable and meaningful pedagogy is a significant challenge. Overcoming these teaching issues is not an easy task in classrooms dominated today by systems of examination, accountability and teenage socialisation.

10.18 New Zealand University Geology Students

Figure 10.28 in Appendix 6 shows the UC first year student results for question 3, Section B.and Table 10.12 and Figure 10.29 compare results for Section B, question 3. Few of these first year geology students (9%, n =12), were able to correctly estimate the ‘beginning of time’ in relative time event terms from the GeoVAT instrument. However, 42% were able to correctly estimate the formation of the Milky Way Galaxy. It seems that connecting the origin of the Earth with the evolution of the universe is too difficult. Overall, first year geology students equally underestimate and overestimate the relative bio/geological events with only on average, 40% of all questions being correct.

Table 10.12. Comparison of UC Geology students' results for ideas about fossils.

Question 1 Section A GeoVAT (N = 48)	UC Ist Year (n = 28)	UC 2nd Year (n =10)	UC Post Graduate (n = 10)
1. Fossils are from seeds in rocks	100%F	100%F	100%F
2. Fossils are failed creations of God	96%F	100%F	100%F
3. Fossils are tricks of the devil	100%F	100%F	100%F
4. Fossils are accidents of nature	82%F	100%F	100%F
5.Fossils are preserved parts of once living organisms	96%T	100%T	100%T
6. Fossils are preserved remains of extinct org .only	100%F	100%F	90%F
7. Fossils are important & interesting	100%T	90%T	100%T
8. Fossils support the fact of evolution.	89%T	90%T	100%T
9. Charles Darwin first person to think of evolution.	43%F	20%F	40%F
10. Humans are evolved from apes.	61%T	70%T	90%T
11. Oldest know fossils are 3.4bya	68%T	80%T	90%T
12. A scientific theory is a guess.	75%F	80%F	70%F
13. Birds are from dinosaurs.	64%T	70%T	70%T
14. Earth was made in 6 days.	79%F	80%F	100%F
15. Common DNA code.	68%T	80%T	80%T
16. Punctuationism.	39%T	40%T	50%T
17. Gradualism.	93%T	90%T	90%T
18. The Sc. method is controlled testing only	64%T	80%T	30%T

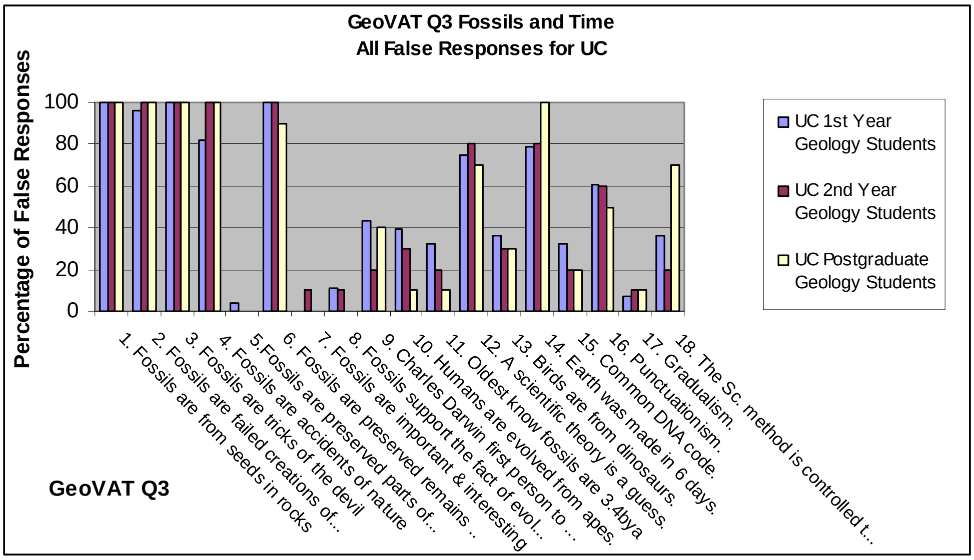


Figure 10.29. Responses recorded as 'False' for Section B, Q3 GeoVAT.

A multi-variate cluster analysis (Figure 10.30) of UC data from Table 10.12 for ideas about fossils (GeoVAT Section A, question 1) shows three distinct groups of responses. It seems that there are stereotyped conceptual confusions about how science investigates natural phenomena as well as an ignorance of the importance of stasis, species extinctions and rate of evolutionary change. Even postgraduates have an immature view of the history of evolutionary thought as shown by 60% of responses indicating that Charles Darwin was the first to think of evolution. Teaching the history of scientific thought is fraught with difficulties at secondary level, and it is common to have little recognition of this topic in curricula. It is also likely that science teachers have little training in this area.

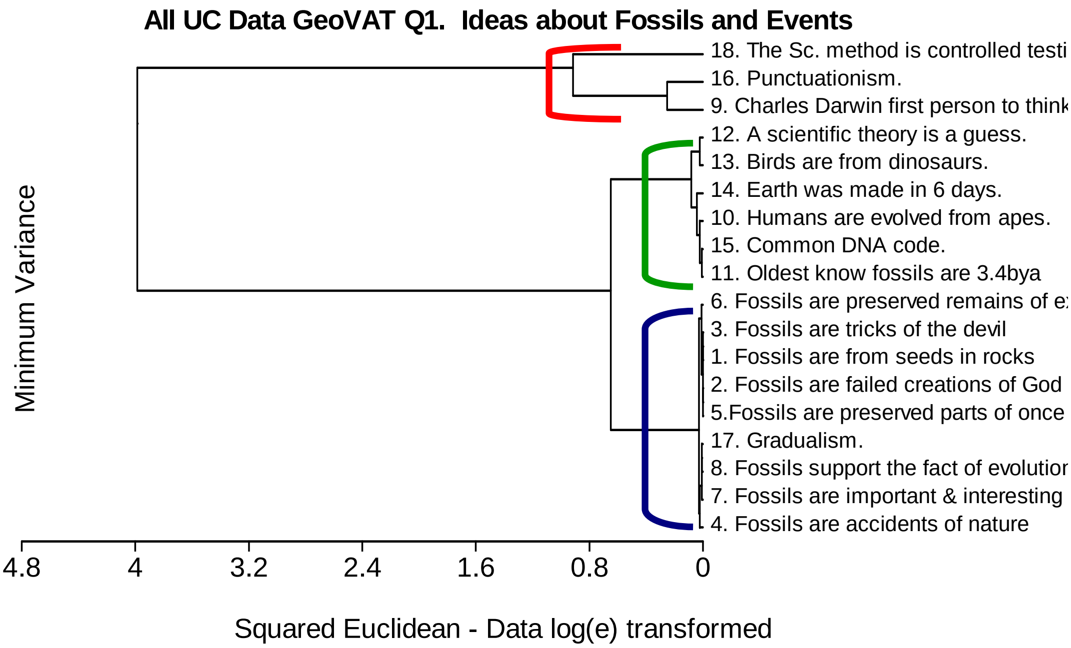


Figure 10.30. Cluster groups for all UC Data for Q1 GeoVAT: Ideas about fossils.

Surprisingly, most post-graduate students also considered Charles Darwin to be the first to think of evolution. The history of science is rarely formally taught as an integrative topic within the sciences and most students will learn by ‘osmosis’ and as the moment, interest and need occurs. 25% think a scientific theory is just a guess and 14% think the Earth was made in six days (8/58 were creationists). 90% think evolution is gradual and 43% thought new species do not appear suddenly in a punctuated fashion. In common with other cohorts, 58% thought ‘the’ scientific method is only the controlled fair testing of hypotheses suggesting that other valid scientific methodologies are poorly understood or used. This is a significant teaching challenge to implement.

The postgraduate geology student cohort of 10 students unsurprisingly (and thankfully) recorded the highest percentage (80%) of correct responses for section B question 3 (Figure 10.31, Appendix 6). This cohort has the advantage of experience, age and training. However, except for first year and second year geology students where events were underestimated this cohort overestimated the events. There still appears to be elements even at postgraduate level, of relative time comparisons of the given events (i.e. internal relativities) rather than estimates based on factual knowledge.

10.19 Chapter Summary

This chapter specifically addresses research question one:

How do students aged between 12 and 40 develop their conceptions of the fossil record and geological time?

This chapter also looks in detail at the place of teaching and learning aspects of biological evolution within the New Zealand national curricula and the conceptual status of students from a wide age range and educational background. There is poor curricular linkage between geological science, paleontology and paleoecology with general concepts of biological evolution within the NZ national Science curriculum of which Biology is a strand: *The Living World.* The reasons for this are likely to be related to course structures in teacher training and the dominance of molecular genetics (rather than the connections between population genetics, biogeography and paleontology) as a context in school Biology courses. These in turn, are controlled by national assessment standard criteria rather than holistic views of curricula. Selected student concept maps are offered as an illustration of typical conceptualisations of 16/17 year old New Zealand students studying Biology (Figures 10.1 and 10.2). These conceptualisations range from atheistic views to the incorrect regurgitated rhetoric of creationistic pseudoscience.

This chapter also examines cohort responses to the GeoVAT evolution related questions from a wide age range and different culturally set institutions. It appears that the understanding and perceptions of scales of time and the conceptualisations of the significance of the fossil record are much the same for all age group cohorts and across these different cultural settings. This may reflect curricula evolution. Responses to ideas about fossils and relative bio/geological events indicate that as age increases the degree of overestimation and underestimation of relative diachronic events decreases. It also seems that all age groups still consider that science methodology operates essentially by a stereotypical ‘fair’ and controlled testing of hypotheses with a limited understanding that the geological and biological sciences often use ‘pattern’ seeking techniques using distributions of minerals or species as well as historical and comparative data. The concept of punctuationism as an explanation for evolution as seen in the fossil record is subordinate to the view of gradual evolutionary speciation. On top of this, most responses (incorrectly) indicate that Charles Darwin was the originator of the concept of biological evolution with little knowledge of the historical roots of this concept. In concert with other recent work on differences between Biology and non-biology majors and their teaching of evolution and the impact of teacher preparation for teaching evolution (Nehm, & Schofield 2007; Nehm, Sun Young Kim & Sheppard, 2009) much work is still needed to explore the reasons why there is so little difference in this study’s age cohorts having similar conceptual status for the understanding of fossils, the fossil record and ‘Deep Time’. Placing these geological concepts into teaching, learning and curricula reforms is a significant challenge for future educators.

CHAPTER ELEVEN

GeoTSAT – GEOLOGICAL TIME QUESTIONNAIRE RESULTS

11.1 Introduction

This chapter summarises and discusses the findings of different age group cohorts with regard to conceptions of geological time and addresses research question 3: What is the influence of diachronic thinking on conceptions of geological time? Cohorts surveyed include:

1. American University of Beirut (AUB) primary and secondary school teacher trainees.
2. University of Canterbury (UC) secondary school teacher trainees.
3. Israeli Grade 8 and 10 students (ages 13-15 years).
4. UC first year, second year and post graduate geology students.

As stated in Chapter 6, nothing in geology (and biology) makes much sense without reference to time. Geological time is often expressed as ‘Deep Time’ hinting at the complexity of comprehension rather than complexity of the concept. It forms a cornerstone of geological education and is a defining characteristic of learning in geological science. The second research question asks: How do students aged 12 to 40 years of age develop their conceptions of the fossil record, geological time and geological structures. GeoTSAT is a validated instrument used to gather data on geological time and spatialisation (See Chapter 5 for details and results reliability). The rationale for use of a previously validated questionnaire is also outlined in Chapter 5. This questionnaire contains conceptual questions about relative geological time and elucidation of geological histories.

11.2 About the Instrument Questions

Questions 1-5 ask about geological history and relative geological time. Some spatialisation skill is needed for interpreting block diagrams and the folded strata diagram (Appendix 2). Importantly, some ability to connect geological environments with rock type is also required but at a low level. Along with interpreting a geological history, correlation of rock strata by recognition of equivalent or relative age is also tested. No questions were asked of comprehension of absolute geological time except in the GeoVAT instrument where responses were invited for students to provide an absolute age where known. Interestingly this section was the least responded to. Figure 11.1 illustrates the difference between relative and absolute geological time measurement.

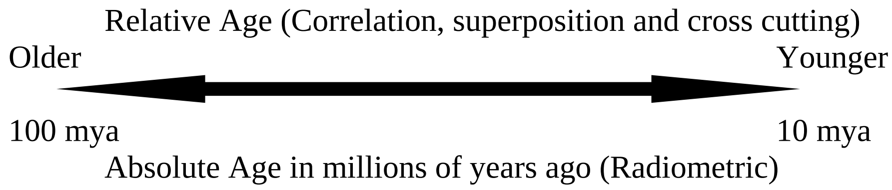


Figure 11.1. Times Arrow: Relative and absolute geological time.

11.3 Findings for the American University of Beirut Secondary School Trainees

Students in this cohort of 21 secondary school trainees from the American University of Beirut (AUB) have a mean age of 22 years. Religious affiliation is dominantly Islam (Druze) (76%) and Christian (24%). In common with other cohorts of non-geology specialists there is generally a low value placed on the study of geology. For this cohort, 61% considered Geology to be of low importance. Respondents also considered plate tectonics, landforms, earthquakes and volcanoes to be the most interesting geological topics with evolution, fossils, and mapping to be the most troublesome topics. The complete GeoTSAT questionnaire can be viewed in Appendix 2. Tables 11.1, 11.2 and 11.3 show results for AUB secondary school trainees for questions 1b, 3 and 4 of the GeoTSAT questionnaire.

Table 11.1 Question 1.b results: Age order of fossil.

n =17	**Gastropod 1 Oldest**	**Trilobite 2**	**Clam 3**	**Ammonite 4=**	**Coral 4=**	**Snail 6 Youngest**
% Correct	82%	23.5%	23.5%	17.5%	58.8%	64.7%

Q.1.b. Naming fossil of the same age (n = 18)

Ammonite and Coral = 44%

Coral and Snail = 33%

Clam and Ammonite = 5.5%

Ammonite, clam and gastropod = 5.5%

Did not do (DND) = 11%

Q.1.c. Actual responses in accounting for the formation of the rock exposure.

- “Drought
- Layer of sand provides habitat. Layers build on top of one another due to the weather such as hurricanes. This causes rocks to break.
- Layers over one another one covering the older one.
- Gastropod found first – others on top.
- “Caused by earthquakes and storms”.
- Animals are trapped in sand due to erosion. Layers of earth have sedimented on each other.
- Sand covering layers.

Q.2. A Geological history. Response transcripts.

- “Sea to land (trees) to Sea
- One layer covered by another with teeth in it. After erosion of a layer another one on top.
- Oldest at the bottom. Ocean limestone – water level dropped- soil replaced sea floor then ocean. (Correct sequence but no details).
- Some just repeated the layers as given.
- Sharks teeth shows once ocean and trees as land (No explanation of sequence).
- Deep water then evaporated with the sand becoming rock.
- The ocean dried up and land ‘took over’, then flooded”.

Table 11.2 Q.3. Distribution of fossil ages based on **relative dating** of strata (my = million years).

Age	<80my	85	90	95	100	105	>110
Snail	**5**	**8** (50%)	**1**	**1**	**0**	**0**	**1**
Coral	**0**	**1**	**3**	**8** (47%)	**4**	**0**	**1**
Clam	**0**	**0**	**1**	**0**	**0**	**8** (50%)	**7**

Making a connection between the numerical scale of 5million year intervals and the biostratigraphy (strata or rock layers with fossils in them) is not always clear as roughly 50% were incorrect for each stratum. Interestingly, there is overestimation at the older end and underestimation at the younger end. All students managed to identify that the relative coral stratum is in between 90my and 100my because of the given boundaries.

Table 11.3 AUB Secondary teacher trainee responses to question 4: Correlation of strata.

Response	**Shark 1 Oldest**	**Urchin 2**	**Snail 3**	**Fish 4**	**Brachiopod 5**	**Gastropod 6**	**Clam 7**	**Coral 8**	**Ammonite 9**	**Trilobite 10 Youngest**
1	1	2	3	4	5	6	7	8	9	10
2	1	2	3	4	5	6	7	8	9	10
3	3	5	1	2	8	7	4	6	10	9
4	1	2	3	4	5	6	7	5	9	10
5	1	3	2	8	7	5	6	4	9	10
6	1	2	3	8	5	6	7	4	9	10
7	-	-	-	-	-	8		7	9	10
8	1	2	3	4	5	6	7	8	9	10
9	1	2	3	4	5	6	7	8	9	10
10	1	2	3	4	5	6	7	-	9	10
11	2	2	1	4	5	10	9	8	7	6
12	1	2	3	4	5	6	7	8	9	10
13	3	6	2	10	5	1	4	7	8	9
14	9	10	6	2	4	7	8	3	1	5

6/14 correct = 43% for completely correct answer.

Q.5. Only 3 attempted this question and all were very confused responses.

11.3.1 Results Discussion

Questions 1 a – c attempts to probe student understanding of the relative age of strata using a key fossil for each strata or rock bed but with folded strata. The assumptions are that students conceive correctly that the oldest layer is at the bottom (assuming no tectonic overturn), that strata with the same fossils in them are the same age and that the beds were originally horizontal (Steno's laws: see Chapter 2). Results for this small cohort show that many students are unable to order these layers (43% were able to have all correct) into the correct age order. These students are all graduates and training to be secondary school teachers. Identifying that the ammonite and coral were the same age posed a problem for 56% of this group. It seems that for 44% of these students (mean age of 22 years) they were unable to recognise that fossils found in the same strata are the same age. Likely causes are that these students simply look at the pictures of the fossils and their positions relative to one another and fail to connect the strata with the fossil type and their relative age. This is supported by the fact that the coral is higher in relative position than the ammonite but students do not recognise these two fossils as being in the same layer. In fact, 33% stated that the coral and snail were the same age suggesting that because these fossil pictures were at the same 'height' above the ammonite they are considered to be the same age. Interestingly only one response suggested that the ammonite and the trilobite were the same age even though they were roughly at the same 'height' to each other as the coral and snail. I can not explain why one student stated that the gastropod, clam and ammonite were the same other than random disinterest choice. It is also likely that students do not connect the folded nature of the rock layers with their relative ages. They do not seem to be able to 'follow' the beds horizontally and make the right connection with the fossils they contain.

Question 1c was designed to elicit student understanding of a simple geological history in explanation of the cross section in question 1a (Appendix 2). Unfortunately very few attempted this question, but of those that did, explanations indicate very little understanding of possible geological events, other than recognition that there were layers of rock one on top of the other. There was little connection made between the fossils represented in the layers and their biological and geological environments i.e. there was no connection with a marine environment.

Question 2 also elicits response to explanation of a geological history but provides information on rock type and fossils. Responses suggest that there is a general lack of understanding of rock sequence conformability in terms of deposition and the geological environment. Students appear to connect "bits of tree" with whole trees and therefore land. As I question 1c, the main difficulty seems to be connecting the geological environment with what the fossils mean. No response recognised a repetition or alternation of rock sequence and no response indicated a reason as to why there were no fossils in the repeated sequence. There was no recognition that the top bed was identical to the bottom bed and therefore had a similar geological origin.

Question 3 required students to make an absolute age estimates of fossils based on their relative positions in a rock sequence. Results are shown in Table 11.2. Absolute ages were provided for two igneous rock layers. Around 69% of responses correctly identified the youngest fossil as being less than 90 mya but this was split between assigning 85 or 80 mya. Based on work by Tretter, Jones and Minogue (2006) and Trend (2000a), students probably do not see any difference between 85 and 80 mya: it is just younger than the layer below it. Connecting the given relative ages as absolutes also provides a challenge. It is surprising that three responses indicated that the age of the snail was older than the 90mya igneous rock layer. Perhaps this indicates disinterest and therefore 'anything goes' or a genuine ignorance of the law of superposition. Similar reasoning goes for the oldest fossil at the bottom of the sequence. However, responses to estimations of the age of the coral in the sequence are more revealing. The reasoning is that the known age of the igneous layer above is 90my and the age of the igneous layer below is 100my, but many students seem unable to decide that the age of the coral must be 95my. This is shown by less than 50% of responses being correct but with 29% guessing an impossible age of older than 100my age. Do these students really understand the law of superposition or have they just guessed? Furthermore, these results are typical of responses from age groups from 13 to 23+ years..

Question 4 is a correlation exercise where an assumed knowledge base is that students know that rock layers containing the same fossil type (index species) are of the same age. They are asked to put the sequence in the correct relative age order. Results shown in Table 11.3 reveal that less than half of this cohort of secondary trainee teachers and university graduates were able to correctly identify the correct complete sequence. Shaded responses show where individual responses differed from the accepted sequence. It is likely the stumbling block is that if the student looks at the snail in the centre top and correlates it with the snail in the right hand column and the third layer down, what is underneath will not make sense because they are not the same fossil. If the student correlates the gastropods first, there is a better chance of correlating the other layers. The ability to make multiple correlations is absent in those incorrect answers. The problem for this question was the recognition that not all sequences were identical such that the fish scale underlies the snail in the right hand column but not the centre: hence confusion. It is interesting that 29% of responses failed to identify the oldest layer as that containing the trilobite despite the fact that there is nothing else below it.

Question 5 was unfortunately only attempted by three students with insufficient evidence for any kind of meaningful discussion. Perhaps the spatialisation required for the cross sectional diagram was a challenge too difficult and too long for respondents to overcome. Indeed, it seems ubiquitous that questionnaires that require thinking about and spending time on respondents become more selective and less reliable as the completion time increases. One response, however, indicates a connection between tectonic forces and igneous intrusion and another comment suggest that earthquakes are responsible. There was no attempt to connect geological event possibilities in a correct time sequence.

11.4 Findings for American University of Beirut Primary School Teacher Trainees

Responses to **Question, 1.a** indicate that primary trainees also have difficulty identifying the equivalence in age between the ammonite and the coral. And likely for the same reasons: perception of vertical and lateral positions coupled with the difficulty of connecting the folded stratal contacts with the law of superposition. Although the majority of both primary and secondary trainees correctly identified the youngest layer, it is surprising that some didn’t (37%). This may be due to random sabotage and disinterest or genuine misconception.

Question 1.b. acts as a 'triangulation' reference for Q.1.a.: the conceptual principles are the same. There is significant difference between primary and secondary trainees in responses to Q.1.b. Although less than half of the secondary trainees were correct (44%), only 15% of the primary trainees were able to recognise the age equivalence of the ammonite and coral. However, twice as many secondary trainee responses indicate the age equivalence of the coral and snail as primary trainees. Fortunately only one response from both primary and secondary indicate the age equivalence of the clam and ammonite! The one response indicating that all of the fossils had different ages can not be explained. In any case, about 10% of both sets of trainees stated they did not know, suggesting that they genuinely could not work it out or could not be bothered.

Actual responses for Q1.b for naming fossil of the same age

- Ammonite and Coral = 15%
- Coral and Snail = 15%
- Clam and Ammonite = 0%
- Ammonite, clam and gastropod = 0%
- None the same age = 5%
- Did not do (DND) = 50%
- Don't know = 10% (n =20)

Responses to Q1.c. suggest that few primary trainees were able to connect geological events to explain the diagram. There was recognition however that the strata had been altered in some way such as by compression. There was no connection of environment of formation with the fossils found in the strata.

Examples of responses in accounting for the formation of the rock exposure for Q.1.c.

- "Earthquakes and mudslides"
- "Soil piles up to form layers"
- "By compression forces."
- "Rock sediments might have been entrapped in the layers which have been subjected to compression".

Q.2. Again, only one response. This response indicated however, knowledge of plate tectonics, marine environments and an implied uplifting, but these ideas were totally disconnected from the problem and was a typical immature response where only known concepts were stated but completely disconnected from the purpose of the question.

Q.3. Distribution of fossil ages based on relative dating of strata (Table 11.4).
Making the connection between an absolute date and a relative date also poses difficulties for both cohorts. There is little evidence of recognition that the most likely age for the coral is in between 90mya and 100mya. As a result, answers are exaggerated as too low or too high. This relativity of scale is worthy of further research. Although the response rate is too low for conclusionary discussion, it seems that primary trainees are similar to secondary trainees in their responses to Q.3. Students are able to give an absolute age based on relative position in the strata that is correct, but it is often over and under estimated as if the absolute age is known but perceptions of this number are not trusted. Q.3 also acts as a 'triangulation' for ability to interpret relative time.

Table 11.4. AUB primary teacher trainee results for Q.3. (Number of responses).

Age	**<80my**	**85**	**90**	**95**	**100**	**105**	**>110**
Snail	2	1	1	0	0	0	0
Coral	1	0	0	3	0	0	0
Clam	1	0	0	0	0	1	2

Question 4 (Correlation) appears to be too difficult for this cohort (rather than dismissed). This question also cross references with previous questions but with the added dimension of 'missing' strata at separated locations. For example the ammonite is missing from the third location column and the fish scale is missing from the second location column. Figures 11.3 and 11.4 details the logic of strata correlation. Students were not asked to explain this as the key conceptual question concerns geological correlation rather than geological history. Question 5 asks for a geological history. Understanding geological correlation appears to not be part of this cohort's conceptual ecology presumably as a result of inadequate training or genuine misconception.

This class of 21 primary trainees appear to be less confident in identifying the correct relative time order from a simple stratigraphic column than their graduate secondary school trainee counterparts. For example in Table 11.5, only half the primary trainees managed to correctly identify the gastropod as representative of the oldest strata whereas the majority (82%) of the secondary trainees were correct. On the other hand the reverse was true of correctly identifying the trilobite as second to oldest.

Table 11.5 AUB primary teacher trainee responses to question 4: Correlation of strata. (Numbers are the number of responses recorded).

Respondent (n = 14)	**Gastropod 1 Oldest**	**Trilobite 2**	**Clam 3**	**Ammonite 4=**	**Coral 4=**	**Snail 6 Youngest**
1	3	5	1	4	2	6
2	3	2	1	5	4	6
3	-	-	-	None	-	-
4	6	1	4	3	5	2
5	3	2	4	1	5	6
6	1	2	3	4	5	6
7	1	2	3	4	5	6
8	1	3	2	6	4	5
9	4	1	5	2	3	6
10	1	3	2	4	6	5
11	6	5	1	2	3	4
12	1	3	2	4	5	6
13	1	2	3	4	6	6
14	1	2	3	4	5	6
% Correct	50%	43%	29%	50%	43%	64%

Q.5. Student responses to relative age order of strata (assumes no strata overturning) Only one student attempted this question with all others (n = 10) recording that they had no idea (Figure 11.2).

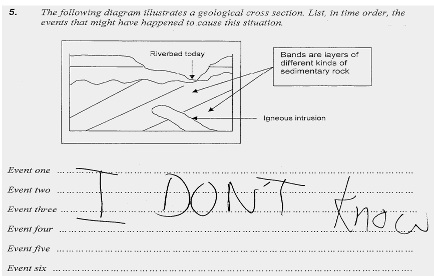


Figure 11.2. Typical response from AUB primary trainees for Question 5 GeoTSAT.

11.5 Summary

This cohort of primary school trainees indicate a similar response and conceptual status to primary school trainees in New Zealand and is also typical of all other cohorts. For example, expressing a geological history for question 5 is difficult and requires a clear understanding of relative geological events and knowledge of superposition. Connecting relative with absolute ages is generally manageable but many students struggle and connecting geological events with geological environments poses a general difficulty. Teaching and learning the connections of geological processes, evidence and environments seems to be missing.

11.6 Israeli Secondary School Student Responses to GeoTSAT

The GeoTSAT questionnaire was given to two different age groups:

1) Geology students in Grade 10 who have just began to study Geology. Fifteen students 16 years old and 66% female answered the questionnaire.
2) Geography students in Grade 8 (13-14 years old) mixed and higher ability began studying 'Introduction to Earth Science' the previous year. Twenty one students from a class of 26 responded; five students who did not respond to the questionnaire. This outcome is typical of most questionnaires.

11.6.1 Précis of the Co-ordinators and Translators Comments

The Grade 8 class was of mixed and high ability. Questions that had connection to depositional environments were quite easy for most of the students of both the geology and the geography classes, perhaps reflecting managed and accessible fieldwork with good rock exposures. This is in contrast to the New Zealand responses and all other cohorts, again perhaps reflecting curriculum issues, local school traditions such as whether fieldwork is undertaken, teaching strategies and student conceptual status and interest. Structural geology questions (7 and 8) were also quite easy for the Grade 10 students but very difficult for the Grade 8 students. Grade 8 and 10 students did not answer question no. 2 and 5 as it appeared too difficult for them. Table 11.6 presents the results of the Israeli Grade 10 responses to questions 1-5 of the GeoTSAT questionnaire.

Table 11.6. Israeli (IS) Grade 10 results to GeoTSAT (Q's 1 – 5).

Question No. (n = 15)	**Good answer**	**Partial answer**	**Wrong answer**	**Did not give any answer**
1a (marine layers)	12	3	0	0
1b	12	1	0	2
1c	6	4	0	5
2 (Rock layers)	-	-	-	-
3	12(80%)	1	1	1
4 (Correlation)	11		1	3
5 (Geological sequencing)	9	1	0	5
Rounded Means	10 (67%)	2(13%)	1(7%)	3(20%)

11.6.2 Summary of Israeli Grade 10 Results

With 80% of these 13/14 year olds with correct responses for question 1a, placing strata in relative time order appears not to be difficult for this cohort. This outcome suggests that students of this age are able to recognise the folded nature of the strata and not misperceive the relative positions of fossil icons as is common in other cohorts. Similarly, placing the fossils in the correct age order posed little difficulty. However, when asked to describe how the rock exposure (Q1.c) might have been formed (this may require a verbal explanation from the person in charge), only 40% were able to do this. Typical responses indicate an interpretation of the question to mean providing an explanation for "what the exposure looks like in the picture" rather than connecting geological principles to an explanation: a universal difficulty of students answering questions that have a deeper meaning.

It is difficult for this age group to visualise and connect abstract geological environments to a 2-D structure. Teenagers can resort to superficial answers, and in support of Dodick & Orion's findings (2003), students need to also apply their conceptual understandings of superposition to override the relational placement of fossil icons (See Appendix 2). In addition, the ability to understand the significance of an index fossil to strata is also needed to fully develop an answer. Question 2 was not answered by any in this cohort. Clearly, question 3 (assigning absolute ages and conceptualising relativity with strata) posed little difficulty with 80% being correct. The correlational exercise (Q.4) also posed little difficulty indicating that at age 13/14 years the ability to correlate geological strata where there is missing strata has already developed. Those students (n = 9/15) who answered question 5 (Sequencing) also were correct in determining the correct age sequence but unfortunately did not supply written answers of explanation so there is no information of conceptualisation of geological environmental connections with just placing the sequence of events. These results support the co-ordinators view that they are an excellent group and significantly more advanced than the Grade 8 cohort.

11.6.3 Israeli Grade 8 Results for GeoTSAT Questionnaire

Table 11.7. Israeli (IS) Grade 8 results to GeoTSAT (Q's 1 – 5).

Question No. (n = 21)	**Good answer**	**Partial answer**	**Wrong answer**	**Did not give any answer**
1a (marine layers)	19	1	1	0
1b	16	0	0	5
1c	13	0	0	8
2 (Rock layers)	2	1	0	18
3	8(38%)	5	1	7
4 (Correlation)	4	7	0	10
5 (Geological sequencing)	-	-	-	-
Rounded Means	10(48%)	2(11%)	0.3(2%)	8(38%)

11.6.4 Summary Discussion of Israeli Grade 8 Results

Table 11.7 presents the results of the Israeli Grade 8 responses to questions 1-5 of the GeoTSAT questionnaire. Although there were more of these 10/11 year old students not responding to the questionnaire, fewer provided incorrect answers compared to the grade 10 students. This cohort also shows that they are able to correctly place strata into a correct relational order. However, for question 3 significantly more students were correct in assigning an absolute time suggesting that this relationship between relative and absolute time as expressed in a column is more difficult for the grade 8 students. Both groups were considered excellent students by their co-ordinator. Some students were also able to correctly sequence the geological events for question 2. Question 4 posed a greater challenge for these younger students than the grade 10 students. The number not attempting, partial answers and incorrect answers were greater than the grade 10 students. Unfortunately no students attempted the sequencing question. It seems that these 10 /14 year olds **are** able to identify geological age relationships.

11.7 New Zealand Secondary School Student Responses

11.7.1 Year 11 Demographics

This small cohort (n =13) of typical year 11 students at Ashburton College (AC) had a mean age of 15 years and 8 months. Reflecting a rapidly changing demography, two were born in Australia, one in Tanzania and another in Kiribati. The most favoured subject was physical education. For this group learning geological science was of no importance and this is partially reflected in the lack of responses. However, those that did respond to various questions provide an insight into perceptual and conceptual difficulties. The most interesting geological topics included formation of rocks, the rock cycle water, weather and volcanoes. The most troubling topics were: pollution, geological sequencing and correlation and the meaning of fossils.

11.7.2 Year 11 Results

Four of this group (31%) were incorrect in their age ordering (understanding superposition) for question one. Responses suggest that these students in common with all other groups look at relative icon placement rather than follow the strata. Those that indicated that the snail and coral were the same age see them as being the "same height" as each other and therefore the same age. Explaining how the clam and ammonite are considered the same age is more difficult other than a random selection of icons.

Question 2 was mostly answered in terms of merely describing what information was given in the diagram with no attempt to link with geological events environments. For example, this cohort's responses show little recognition that rock containing clams and sharks teeth indicate a marine environment and that these organisms were living and dying in this environment. It is quite common for students to fail to make the connection that fossil remains indicate a past life: they tend to focus on the dead fossil aspect rather than the once living aspect. This is an area where a better liaison between biology and geology would improve the connections of paleoecology with fossil remains. In common with other groups, *"bits of trees"* also means, for 30% of responses, mature living trees and a terrestrial environment rather than bits having been transported and become part of sediment on the ocean floor. All 13 responses were correct for question 3 suggesting that reading a relative stratigraphic column is not a major difficulty. Although only four responded to question 4 on correlation there appeared to be little difficulty in applying the 'correlation rules' (Figure 11.3), suggesting this age group are quite able to solve relativity problems. Unfortunately there was only one response to question 5. This response indicates significant difficulties applying the superposition and cross cutting rules. Question 6 posed few problems for the 11 responses as all were correct (62% were female).

11.7.3 Year 13 Results

Again, a small cohort of 14 students, but one that also reflects an increasingly diverse ethnicity, cultural and scholastic backgrounds of students from Zimbabwe, China and Romania. The most favoured school subjects for this cohort were physical education, English, and Biology. In keeping with a wider subject selection policy than Year 11, learning Geology was of little interest to this cohort (See Chapter 9 for details of the NZ science curriculum). The most interesting geological topics for this cohort included: the fossil record, volcanoes and the formation of rocks and the most troubling topics involved understanding earthquakes, how fossils and rocks are formed and for the single 'creationist' thinker, evolution. Conceptual conflicts are rarely expressed but questionnaire responses indicate their presence.

Only a single response was incorrect for questions 1a and 1b suggesting little difficulty in perceiving geological structure and relative ages of strata. The incorrect response was the same as many others matching icons relative levels rather than following the folded strata. Students expressed the following key explanations:

> *'Folding of tectonic plates pushing together*
> *Movement of earth causing unstraight lines*
> *Streams could have washed away the rock sediment to form the vallies and sand storms could have gathered to form the peaks.*
> *Volcanoes erupted'*

It seems that a common conceptual theme is a focus on the easily observed structures rather than the explanations. Students in general do not see the folded strata in a diachronic sense. That is, strata are not seen to represent the passage of time and explainable through paleogeological environments based on the internal evidence of the sediment and consequent structural history. There is a tendency to connect disparate geological terms without explanation.

Students were able to recognise the cyclicity of strata but generally provide descriptions and (again) little geological environment explanation. This is also in my teaching experiences, typical of other subjects of learning especially where a certain level of literacy is required. There was recognition of sea level change but there was no connection with the effect of this on sediment deposition. In common with other age groups, *"bits of trees"* is connected only with land and not transport and sediment depositional processes.

Only two students were incorrect for assigning an age for question 3. Students consider the age to be relative to the number given rather than the relative position of the strata. That is, the snail is 95mya because counting is taken forward from 90 to 95mya. The clam was correctly aged as going down from 100 to 105mya.

Seven responses (54%) were incorrect for the strata correlation of question 4. It is difficult to explain the various combinations as there appears to be no logic. For example, the gastropod and clam were considered to be the youngest and in one case, the coral was considered to be the youngest. Correlation is a problem for many in this cohort in that recognition and comprehension of missing strata is a mystery.

Responses to question 5 on writing a sequence of geological events were very elementary and in effect, simply describe the obvious features such as the tilting and intrusion. There was little evidence of superposition and cross cutting relationships. The unconformity was identified in some cases but not understood. Several responses stated the intrusion as the first event as "it was at the bottom". This suggests an ignorance of cross-cutting relationships.

11.8 University of Canterbury First Year Geology Students

The mean age for this cohort of 29 students was 20 years and 5 months. Their most favoured school subjects in order were: Geography, Biology, Physical Education and then Science. None had studied geology after Year 11 (at age 15). Learning geology was unimportant for 21% of this group, significant for 41% and very important for 40%. The most perceived difficult geological concepts included mapping, naming fossils and visualising geological structures. Conceptualising geological time did not appear to be a problem for this group and the time honoured necessary drudgery of needing to have specific knowledge such as taxonomic names of fossils, names of minerals and rocks and a very large jargon continues to take its toll on learning.

11.8.1 First Year Geology Student Results

Responses hint at a conceptual status. All except two students were able to correctly identify the relative ages in the deformed cross section for question 1, and for question 1b two did not recognise the equivalent age of the ammonite and coral, implying that some students of this age group are still 'distracted' by the deformed strata. This is in common with other errors from younger age groups where the answer given was coral and snail suggesting a horizontal correlation rather than a vertical one. That is, these students look across and see the fossil icons are at the same horizontal 'level' (See Appendix 2 for diagram) and so must be the same age. Question 1c was poorly answered. Although there was recognition of a marine sedimentary sequence and correct ideas of erosion, deposition and uplift, relatively few (n = 6/29) were able to identify and adequately explain the unconformity.

Question 2 responses were answered in much more detail. Although somewhat confused there was clear conceptual understanding of links between geological environment and rock formation. However, as in other cohorts, there is a tendency (universal?) to simply reword the information given. One response considered the rock material to be a lake, despite the presence of shark teeth and clams, so not all are able to link environment with materials. Bits of trees seem to be associated strictly with land and lakes rather than possible transportation into a marine environment. This suggests that there is little conceptual linkage between sediment type with a marine transgression and regression cycle and associated factors such as water depth and distance from land. Postgraduates were able to do this.

The most common response to question 3 was to ‘sit on the fence’ and state that the age of the coral was “between 90 and 100 million years old” rather than provide an absolute age of 95 million years. There appears to be almost a fear of putting down an actual number! However, the majority who ventured an absolute age were able to correctly provide ages based on comparisons with known values.

Question 4 also probes the conceptual ability to correlate ‘biostrata’ when the sequence is ‘broken’. That is, some strata are absent from some columns but when taken collectively, a relative correlation is possible. More than half (52%) were able to correctly correlate the strata. The most commonly incorrect response was to somehow ignore the position of the sea urchin and placed the shark and the snail as being conformable (i.e. in sequence). There is also the added complication (amongst others) is that the strata below the snail contained different fossils and that the first column has no snail. Correlation for this group has posed considerable difficulties. In common with what Dodick and Orion (2003a) found, most high school students (and older students) employ a ‘vertical’ superposition strategy to correlate rather than a 3-D strategy when translating across different localities. Translating vertical strata across a horizontal plane (and the geological concept of ‘facies change’ and the interfingering of different sediment types on the ocean or lake floor) is a step that even postgraduate geologists are still learning. A geological facies is a horizontal change in environment where different types of sediment are deposited and so a geological column has not only vertical change but also contemporaneous horizontal change. Investigating how students learn to translate 3-D correlation is a future and rich area of research.

The same difficulties of determining the age of the igneous intrusion was expressed for question 5 as postgraduate students: the problem of where to place the igneous intrusion. Most responses place the intrusion after tilting based on the assumption that it was intruded perpendicular to the strata and is now shown as being ‘tilted’. Only 6/23 or 26% identified the unconformity. Of these responses, there was a lack of connection between the need for terrestrial erosion to account for the unconformity. Explanations however were not specifically asked for: just an event time ordering with relatively ambiguous information.

11.8.2 Summary of Results

In Montangero's (1996) work on the development of diachronic thinking in children (See Chapter 2, p.25 for details), it appears that although young children of 7-12 years old are able to recognise differences and order and date observable successive changes, it is very rudimentary. In terms of sequencing and time ordering geological events and strata by correlation, it seems that 21 year olds are able but still in a formative state of diachronic thinking. Although correlation of geological strata (Figure 11.3) requires a temporal organisation in terms of Montangero's schema, question 5 also requires a spatialisation recognition and connection with geographic separation. The following diagram illustrates the complexity of correlation and the need to translate information when there is conflicting information. In fact, the great Devonian controversy outlined by Rudwick (1985) was in essence a 'missing strata' correlation problem.

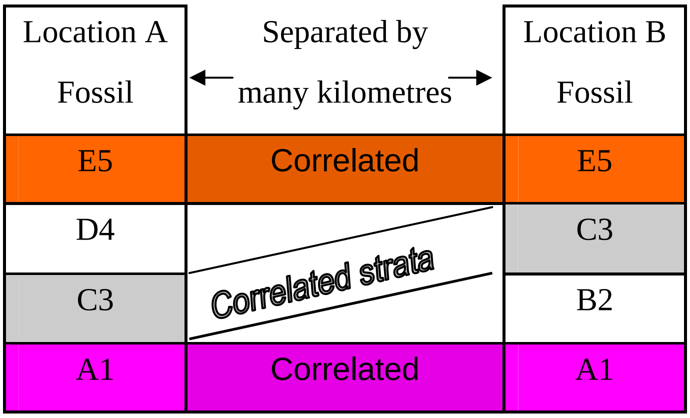


Figure 11.3. Biostratigraphic correlation for **two** locations.(After Dodick, (2007)).

The correlated strata age-order based on fossil content (biostratigraphic), is A1, B2, C3, D4, E5, but location 1 does not have fossil B and location 2 does not have fossil D. This is the key conceptual stumbling block. Complexity increases if several stratigraphic columns from many different localities have different strata and therefore different geological histories but through the same time range.

Linkage with abstract environmental change is an even bigger conceptual step to be learnt and as Dodick and Orion (2003) point out, much can be done to improve the conceptual status of especially middle school students (probably all), especially with integration of fieldwork and 'deconstruction' of concepts of macro and micro time.

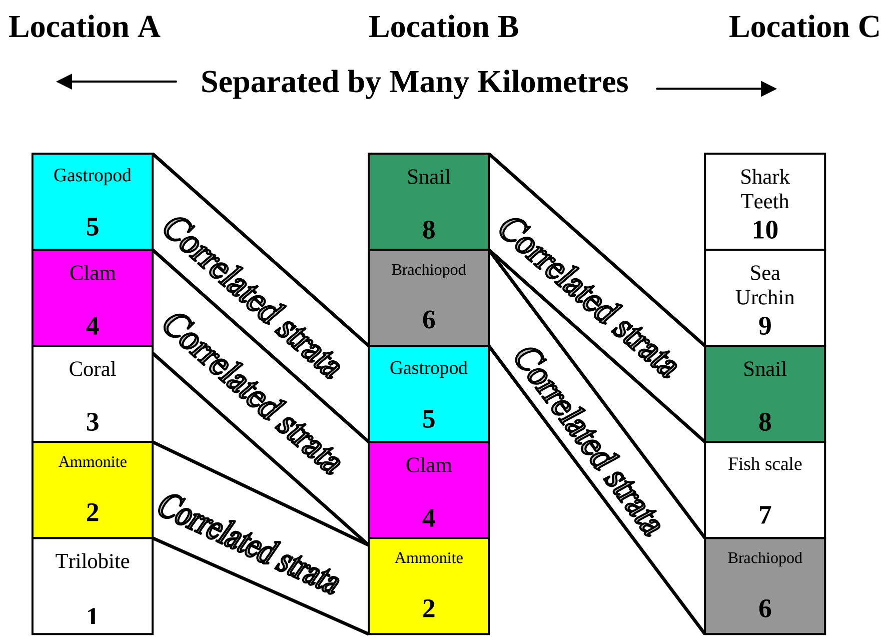


Figure 11.4. Question 4 – Biostratigraphic correlation logic for **three** locations.

The numbers in Figure 11.4 refer to the age order, and the colours show matching age or correlated strata. The empirical knowledge required to solve this correlation puzzle involves knowing that strata with the same fossils in them are the same age (correlated) and that the oldest strata is at the bottom (superposition). There is also an assumption that the stratigraphic columns have not been overturned by folding or faulting. It is also necessary to recognise that the coral (3) is sitting on top of the trilobite strata and is therefore younger, but is below the clam so must therefore be older than the clam. The clam is correlated with location B clam but this strata is absent from location C. Strata 4, 5 and 6 are conformable with the fish scale (7) conformably younger than the brachiopod (6). The fish scale is absent from location C but is older than the snail. The sea urchin and shark teeth are conformably younger than the snail. Reasons for fossil and sediment absence are not asked but are due to either erosion or removal (leaving a decipherable signature) or were never deposited.
Students, who were incorrect for this puzzle, were unable to make sense of the absence in one location column of a key fossil type in terms of its relative age with

those strata **that are** correlated. For example, the coral is absent from location B and C, and fish scales are absent from locations A and B. Strata 9 and 10 are only present in column C. Having three columns adds to the complexity, but in reality, a geologist would work with many columns across hundreds of square kilometres and at different depths. Geologically, correlation enables a sequential geological history and a paleoecology to be inferred: a key aim of geological science. This puzzle is typical of the kinds of problems (3-D and across time) that geological science uniquely deals with. It is not surprising then that the modern use of computer aided 3-D pictures of strata enables a much better visualisation of geological structure. However, 3-D spatialisation remains a challenge for teaching and learning.

11.8.3 UC Second Year Geology Students – Summary of results

The mean age for this small cohort is 23 years and 6 months of whom five were female and four male. Geography was the favoured school subject with biology the next favoured. The most interesting geology topics for this group included: plate tectonics (40%) earthquakes, engineering, evolution and paleontology. The most difficult topics included geological time (40%), structure, paleontology, and optical mineralogy. Do students only dislike the topics they do not understand or is it deeper seated? This entire group indicated a deep commitment to their chosen discipline.

All of this age group were correct in their assignment of relative age relationships with the folded strata distractor not a problem. Clearly this group knows that the oldest stratum is at the bottom. Similarly, most students were correct in putting together a geological history for question two but most missed the idea of eustatic change (climatically controlled differential rising and lowering of sea level and tectonic uplift of land). It was also noticed that there was a tendency to associate sandstone only with a terrestrial environment rather than a marine environment.

Assigning absolute dates for question three to strata sequence was correctly completed by all, but the single creationist view was conspicuous by its prejudice. Although this student correctly identities the absolute ages it seems too hard to resist not to make comment on the unreliability of dating methods, revealing a deeper personal world conceptual view and an ignorance of how radiometric dating actually works.

“90% of dating methods indicate a young age. It is the constant multiplier within the equation that is altered to fit to a long age”. “”Don’t you find it weird that it takes 10 million years for 1m of sediment to be deposited? Shouldn’t it be highly bioturbated”?

These statements reveal just what a difficult conceptual change that many students have to make in learning to accommodate geological processes. Only one respondent recognised and mentioned the unconformity but on the whole, the bigger geological picture is diminished in favour of specific events. One student read the sequence as increasing in age upwards, rather than the conventional geologists way of reading from oldest to youngest as ‘bottom old to top young’.

Question 4 was correctly answered by all, including the young earth creationist, indicating that there is little difficulty in diachronic thinking in relation to strata correlation. The ability to connect geological environments with an accurate sequencing of events for question five proved to be more difficult. The most common problem was deciding on the relative age of the intrusion and recognising the unconformity. Three students) did not specifically identify the unconformity but instead stated an erosion surface implying that rock is uplifted above sea level for surface erosion to occur. Only two students specifically stated the need for subsidence (or sea level rise) to occur for the deposition of sediment making up the unconformity. In short, the responses are generally correct but lacking in detail and explanation and discussion. The timing of the igneous intrusion also caused difficulties in providing a correct explanation.

11.8.4 UC Postgraduate Geology Students

This cohort of ten postgraduate students has a mean age of 26 years and 5 months with the oldest at 36 and the youngest at 21. There were three females. All were born in New Zealand apart from one born in the United Kingdom and another in Papua New Guinea. Favourite high school subjects were: Science 1, Geography 2, Woodwork 1, Outdoor education 1, Physical education 1, English 1 and Maths, 1. Postgraduate status include 1 Postdoc, 1 PhD, 6 Masters, and 2, 4^{th} year honours students. The most disliked sub-disciplines included petrology, geophysics, and geochemistry. Two expressed disinterest in fossils and four expressed the difficulties of geological time and sequence stratigraphy. It would be interesting to explore more about why post-graduates are selecting their specialist fields of study. Fifty percent of respondents were studying aspects of engineering geology such as slope failure and landscape evolution.

11.8.5 Results Summary for Postgraduate Geology Students

Reassuringly, question 1 posed no difficulty for this cohort of postgraduates. All were able to identify the relative ages of strata and consequently identifying the deliberate 'distractor' of folded strata all were able to identify the fossils of equal age.

Question 1c asks for a geological story in explanation of the rock strata shown in question 1a. Although responses were essentially correct, several responses indicate assumptions and preconceptions. Typical responses focus only on the obvious folded nature of the strata and the physical processes involved rather than the importance of the fossil content and the associated paleoenvironmental implications. Several responses stated trilobites as the oldest fossil but this was not a fossil in the sequence implying the application of previous knowledge which is disconnected from the question. Old concepts die hard. Only four responses identified the unconformity and erosion event. Geological unconformities are breaks in sediment deposition and periods of erosion implying uplift for exposure to the atmosphere.

Question 2 asks for another geological history for a sequence of rock strata but with a necessary connection to paleoevironment. Nearly all successfully link geological formation with environment. There are also indications of stereotyped conceptions of lithology and formations such as sandstone being equated with a terrestrial environment rather than eustatic changes of sea level with accompanying different water depth for the sandstone with plant material in it.

Providing an absolute age for **question 3** was incorrectly answered by only one respondent and this corresponded to he non geologist thinking from today back in time rather than the geological convention of working from the past to the present.

Only one respondent was incorrect for identifying the correct ages from the correlation exercise (**Question 4**), implying that identifying relative ages is not an issue although these respondents are experienced and trained geologists (See Chapter 6 for discussion about conceptual awareness of relative geological time).

Question 5 asks for a geological history for deformation (folding of strata), unconformity (time break in deposition and period of erosion) and cross cutting relationships – Steno's laws of superposition. This question posed the greatest difficulties even for this group of experts largely because students recognised the need for more geological evidence to determine the exact relative age than is provided in the diagram. The greatest difficulty appeared to be deciding on the relative timing of the igneous intrusion. The intrusion must be younger than what it cuts through but possibilities include: (a) immediately after deposition of strata while they were still horizontal, (b) after strata had been tilted and uplifted and (c) the youngest event in which the intrusion failed to penetrate the complete sequence.

11.9 New Zealand Secondary School Trainees - GeoTSAT Results

Of this small group of science graduates (N = 12) with a mean age of 27 years and 6 months, five were born in NZ, four in Canada, one in Malaysia and one in China. The oldest student was 44 and the youngest 21. Favourite school subjects include geography (16%), biology (25%), environmental education, chemistry and physics. Volcanoes, plate tectonics, seismology and landforms were the topics students were most interested in with the most difficult being perceived as rock identification, geochemistry and age of the Earth (geological time). Learning geology was of low to medium importance to this group.

Only three responses were incorrect for identifying the relative ages of strata and naming the fossils of equal age. In each of these cases, the distractor of folded strata and position of fossil icon proved difficult for some and in line with other groups. These responses assigned the coral and snail to be equal in age rather than coral and ammonite. Like other groups, it is likely to be the relative positions of icons that determines response rather than looking at the strata. Coral is "the next one up" from ammonite! In effect, the strata are disconnected with the fossil icon.

Question 1c asks for an explanation of how the cliff face exposure may have been formed. Typical statements include:

- “Pressure/folding and weathered down for unconformity
- By earthquake
- Plate compression
- By volcanic eruptions
- Risen up a fault line”.

Although all perceive the obvious two dimensional folded strata, the most common explanation was to state “plate tectonics” as being responsible. Rarely (not only of this age) do students see the strata as having been formed from eroded, transported and deposited sediment. Perhaps it takes too long to write about especially with literacy issues.

Question 2 asks for a geological history. As outlined in Chapters 2 and 6, question 2 requires the application of all of the elements involved in Montangero’s (1996) full diachronic schema and first applied to secondary school students by Dodick and Orion (2003). This cohort (like all others) recognises the obvious repeated nature of the strata but demonstrate little explanatory power in terms of geological change. Change (and more significantly **rate of change**; but this is beyond the scope of this chapter) is the key element to diachronic thinking. Similar to other groups, this group do not connect “**bits** of tree” as having been transported. They just see trees as representative of land and with no connection to the kind of rock material (sandstone) they are embedded in. In other words, fossil remains and rock are disconnected and separate entities and even worse, are not connected to environments or paleoenvironments. This supports Montangero’s findings that the primary source of knowledge needed to contextually conceptualise time is empirical knowledge: the ‘nut and bolts’ facts that understanding links to and the cause of tension between the notion of ‘generic knowledge transferability’ and just plain specific knowledge. For example, if students do not know the connections between water depth and sedimentation principles, then it is impossible for them to connect strata information with geological environment. This seems to be the case until postgraduate geology training level. Furthermore, even although students may have the empirical knowledge they also need the ability to **apply** this knowledge to geological situations.

Only one response was incorrect for the absolute age of the coral for question 3, so this group is able to place a date based on superposition (youngest at the top assuming no overturning).

Out of the six responses to question 4 only three were wholly correct. The problem seemed to be again the inability to apply the logic of correlation as shown in Figure 10.3 where missing strata confuses the relative order of strata. Even having been taught correlation in classroom situations, students still have to be able to apply this to an unfamiliar situation: the learners conundrum and the teachers frustration.

Question 5 again asks for a geological history based on relative age relationships in a vertical cross section. Although not stated as an angular unconformity (One of several different sorts) it was generally correctly identified as a geological event. The tilting of strata was obvious to all but the igneous intrusion again proved a stumbling block in the sense of the ambiguity of its origin. Also, a common approach was to write a geological history from the present back to the past rather than the trained geologists opposite way: old to young. Only the postgraduate geology students wrote a history from oldest to youngest.

11.9.1 Results Summary for NZ Secondary School Teacher Trainees

These 27 year old secondary school teacher trainees are not specifically trained in geology and most are likely to have very little secondary school education in geological science. However, they respond to questions in much the same way as students half their age. They are able to think diachronically and solve basic correlation problems, but lack the empirical knowledge needed to link, explain and express a geological history based on geological on superposition and correlation principles. Connecting geological environments with geological events and placing them in sequential order requires the full application of Montangero's diachronic scheme. This is a considerable challenge for this cohort. Perhaps the physicist Paul Davies should have a final say about time?

"You can't have time without space, or space without time, so if space cannot be continued back through the Big Bang singularity, then neither can time". (Davies, 2006, p.80.)

11.10 Chapter Summary

This chapter addresses aspects of research question 2: How do students aged between 12 and 40 years develop their conceptions of the fossil record, geological time and 3-D geological structures? In particular it presents the results and discussions of conceptual issues related to relative geological time. These are questions 1 to 5 of the GeoTSAT instrument. Note that findings to geological structure problems and spatialisation issues derived from the GeoTSAT instrument are presented in Chapters 6 and 7.

The overall impression is that all cohorts have the same kinds of conceptual difficulties when interpreting diagrams that ask questions about relative geological events and time. For example, linking the significance of geological environments with geological events and which are in the correct chronological sequence poses the biggest difficulties. The ability to correlate strata from different localities that have missing strata improves with age but still provides a challenge for all age groups as even postgraduate geologist responses were not always fully convincing. Similarly, Dodick and Orion (2003) found a significant difference in success at unravelling these relative time puzzles between Grades 7-8 and 9-12. Although not specifically asked, three dimensional aspects such as interfingering of strata on a horizontal plane (technically known as sedimentary rock facies) make up part of an explanation for geological histories and help explain missing strata in correlation exercises. It is unlikely that these structural 3-D aspects of geology are taught at high school and were specifically mentioned by several post secondary geology students as an aspect with which they have the most difficulty.

Although there may be cognitive skills needed to elucidate **relational** evidence of geological time through correlation, there may not be the necessary comprehension of the geological information to determine a **sequential** geological history. This is a significant teaching and learning challenge. It is clear that students who are able to correlate strata are able to transform or use (in Montangero's schema terminology, Chapter 2, Figure 2.2) their experiences, organisational and spatial abilities to place geological strata into a relative time order. All age groups investigated contain students who are able to do this and so are able to make some sense out of geological evidence. As Ben-Zvi-Assaraf and Orion (2005; 2009) have found, connecting students with the real world in fieldwork situations and coupled with well planned pedagogy there are significant benefits for developing not only spatial skills but also diachronic skills: a unique attribute of geological science.

Immature visual-spatialisation ability may be a barrier to perceiving pen and paper exercises but little is known about the development of this ability in the real world, in the field. In general and hypothetically, students' abilities to correlate geological strata appears to be formative at ages 7-12 years, rudimentary at 12 -14 years, early developed at age 16-18 years, developing at ages 18-25 and mature at ages 25-35 years. Investigating this hypothesis would be fruitful.

CHAPTER TWELVE

DISCUSSION
CONCLUSIONS, LIMITATIONS AND DIRECTIONS

12.1 Introduction

> *A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather its opponents eventually die, and a new generation grows up that is familiar with it.* (Max Planck, 1949, p.33)

This thesis takes a broad look at key conceptual aspects of teaching and learning within the geological sciences. As well as the nature of conceptual change, these aspects include crystallising student conceptualisations of geological time, scale, biological evolution, the fossil record, and visual-spatialisation, with particular emphasis on visual penetration ability (VPA).

An important curriculum development of the 1990's was a change in science education direction from the preparation of future scientists within specialist and traditional deductive science subjects such as physics, chemistry and biology, to one of holistic 'science for all' (Orion, 2007a) where education for scientific literacy, citizenship and an informed appreciation of the fragile nature of our planet was paramount. This notion is embodied in the principles of Earth System Science discussed in Chapter 3, p.46. Geological and geoscience learning within local and global curriculum reforms are discussed with New Zealand being a case study for the status of geological education within these reforms. As Orion (2007) again states: "… *it seems that like previous reforms, there is a gap between the rhetoric and the actual change in the classes"*. (p. 111).

In other words, the gap between professional development and professional (and political) change remains very wide. Demonstrable and sustained conceptual change is not easy. The challenge for activating and effecting specific conceptual change within the geological sciences such as the relationship between the fossil record and biological evolution, and development of spatial reasoning, acutely remains. In terms of curriculum reform, New Zealand represents an interesting case where not only has there been an attempt at a conceptual shift in national assessment style and philosophy (Chapter 9 and Appendix 3) but also recent reforms in the Science curricula with, in particular, a shift in the status and role of geological science education (http://www.tki.org.nz/e/community/ncea/sciences.php). Although not always so (E.g. the mid-1800's, USA, (Corgan & Stearns, 2008)), geological science education has always been a difficult area to deal with in curricula especially when related to biological evolution and modern understandings of how the Earth works. As Mayer and colleagues (1995; 1997; 1999) point out, a hierarchical reductionist view of science education might be successful at producing the next generation of physicists, chemists and biologists, but is less successful at enabling a better understanding of Earth's complexly interacting geo-bio environmental systems. Geological science is not environmental/earth systems science. Many of these issues are discussed in Chapters 1, 2 and 9. The overarching purpose of this thesis is to investigate aspects of the conceptual status of students in geological science over a wide age range and different cultures, to investigate the impact of global geoscience reforms and placed within a constructivist paradigm. The key aspects investigated in this thesis are conceptualised in Figure 12.1.

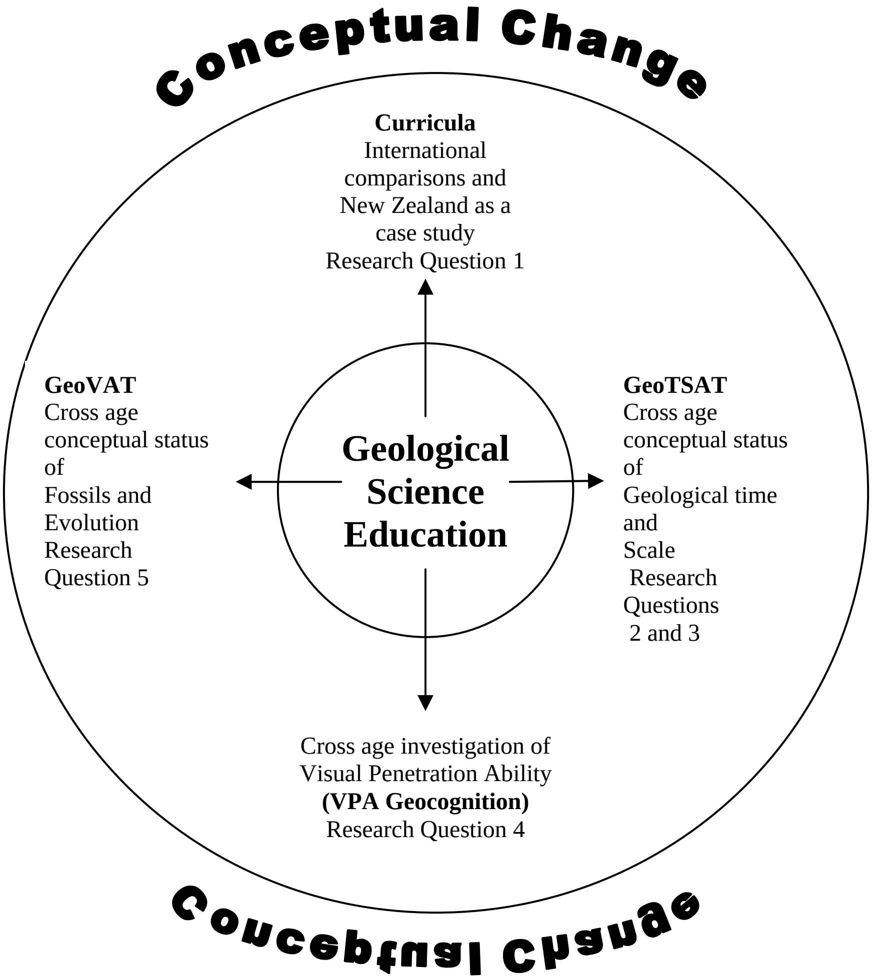


Figure 12.1. Thesis conceptualisation.

The research questions posed in Chapter one included:

Research Question 1

What are the characteristics of international Geoscience curricula and their implementation, with particular case study reference to the New Zealand curriculum?

Research Question 2

How do students aged between 12 and 40 years develop their conceptions of the fossil record, geological time and 3-D geological structures?

Research Question 3

What is the influence of diachronic thinking on conceptions of geological time, structures and fossils?

Research Question 4

What is the influence of visual/spatialisation on conceptions of geological structures?

Research Question 5

How do conceptualisations of fossils, geological time and geological structures vary with age of respondent?

These research questions were investigated using pre-validated and modified GeoTSAT and GeoVAT questionnaire instruments and the use of pre-existing official New Zealand Government data for case study analysis. Data for this thesis were also statistically tested for reliability using Cronbach's alpha.

12.2 Curricula and Geological Science

The year 1957 was significant, being the International Geophysical Year (IGY), and the beginning of nuclear proliferation and the cold war. As a scout in 1962 in Fiji, I remember being in awe of a U2 'spy plane' taking off with jet assisted takeoff and jettisonable wing wheels: a marvel of technology at the time. It ended in the race to the Moon and later, new discoveries were made about the sea floor and its connection to the scientific theory of plate tectonics. From this came new biology, physics, chemistry and earth science curricula. Research question 1 addresses some of the consequences of these reforms from a geological science perspective. Prior to 1957, global curricula were dominated by British educational models and syllabi. In the US, as in many other countries, for example, the 1890's saw geology and geography as the way to learn about the Earth. The Earth Science Curriculum Project (ESCP) (Coash, 1963; Heller, 1963) developed in the U.S.A. was a significant response to the 1957 IGY, where curriculum reform for teaching and learning earth science began in a more modern form. Four years later, the ESCP textbook (American Geological Institute, 1967) appeared and became the main source and inspiration for teaching the earth sciences through the 1970's and 80's. It was a forerunner of Earth Systems Science (ESS) without the focus on environmentalism. About 6% of this widespread and influential textbook was devoted to geological time, geological history and the fossil record. Along with spatial reasoning, they are key elements of geological science and a focus for this thesis. The US K-12 national standards (American Association for the Advancement of Science (AAAS)) for earth science developed in the mid 1990's reduced the influence and dominance of reductionist discipline-based science and to keep pace with the knowledge explosion about our planet (based on information technology) and to keep pace with changing political notions of accountability, assessment and pedagogy.

In the UK, NZ, Australia, South Africa, India and other 'commonwealth' countries, geography was (and still is) an important vehicle for teaching about Earth's physical processes albeit largely from a landform surficial perspective rather than a geological science perspective (See Chapter 1). Geography is seen as an important bridge, linking social science with Science and is the European forerunner of integrating Earth Sciences with environmentalism and people in the form of ESS. In Germany, ESS has started to be developed (Hlawatsch, 2006; Lucken, 2006) but little detail is known of other central European countries and their ESS curriculum developments. The entrenched power and infrastructures for teaching geography in commonwealth countries may be an important factor in the slow uptake of ESS in these countries. In other words, the level of 'Posnerian dissatisfaction' for producing conceptual change may not yet have reached the critical mass for change. In any case, geological science and the geosciences in general, have nearly always struggled to find a meaningful place in an overcrowded, reductionist and hierarchical global science curricula. The curricular tension between the dichotomies of depth versus breadth is well illustrated by the deeper and narrower principles of geological science with the addition of wider and social/environmentalist geoscience approach. The socio/political use of curricular change has increased in some school curricula. This has developed from the Science Technology and Society (STS) of the early 1980's and today's socio-scientific issues (SSI) movements. For example, in the reshaped 2007 New Zealand national curriculum this is shown by an increasing classroom emphasis on the 'social curriculum' in terms of 'key competencies' such as "managing self", "relating to others", using "language, symbols and text" and the nature of Science. New Zealand Levels 6 to 8 (students aged 15 to 18 years) are required to "use relevant information to develop a coherent understanding of socio-scientific issues that concern them, to identify responses at both personal and societal levels" (Ministry of Education, 2007). As Zeidler et al. (2005) and Reis and Galvao (2009) have pointed out, a 'functional scientific literacy' is strongly influenced by discourse, culture, NOS and case based issues. Placing the social aspects in front of the Science as socio-scientific issues de-emphasises the Science.

Key findings and conclusions include:

1. Research question 1 asks about the status of Geoscience (GS) curricula from an international and local perspective. Geological science (GL) is a minor part of international secondary school science curricula and competes for space in overcrowded science curricula.
2. GL as defined in Chapter 1 has been superseded and outcompeted by the introduction of the broader concepts of Geoscience (GS) since the mid 1970's largely as a response to obvious global and local environmental problems. The New Zealand case study (Chapter 9) demonstrates how a Science curriculum reform has enhanced environmental issues and linked them with geoscience at the expense of geological science.
3. Earth Systems Science (ESS) is an attempt (since the early 1990's) at an integrated science course using 'how the Earth works' as the context for teaching environmental values and the nature of science for enabling informed future decision making about our planet (Mayer, 1990). Geological science minimally survives under the ESS umbrella (or in the Australian example, Earth and Environmental science), where little is taught globally (until tertiary level) about geological time, geological history, geological structures, paleontology and paleoenvironments. Geoscience curricula are dominated by the study of earthquakes, volcanoes and plate tectonics and their effects on the environment, people and landforms. A taxonomic approach to GL has given way to a holistic global view of how the earth works and the consequences of feedback loops and cycles associated with the impact of people upon it. The 'nuts and bolts' reductionism and applications of the **science in the geology** has to generally wait in most countries until students are post secondary. As King (2008) points out, there is a real need for more scholarly evaluations of ESS in different curricula contexts and student geocognitive status. The newly implemented ESS aspects of the New Zealand Science curriculum will have to wait for a few years before an evaluation can be made.

4. Socialisation of science curricula has the potential to diminish general science content internationally but in the NZ case study (Chapter 9) GL has been pushed to near extinction. The Science curriculum barrel is full and geological science is the first to go, especially when initially minimal in the curriculum.
5. Implementing GL and GS curricula reforms requires a sustainable pre-service teacher training education infrastructure and professional development that provides more qualified Geoscience teachers into primary and secondary schools. The common global issues for GS and GL teaching (see chapter 2) include: a lack of trained and qualified teachers (Lee, 1995; Vallender, 1997), inadequate funding, political ignorance of the significance of geological science (Thompson, 1997), poorly developed professional development courses and continual science curriculum revisions. Apart from traditionally strong pockets of expertise (UK, Israel, some US states, Japan and some others), there appears to be little improvement in the implementation of GL and GS in the last decade (Orion, 2007b).
6. Assessment drives what is actually taught in secondary school classrooms (and largely, university lecture rooms and laboratory's) because teachers' place first, the provision of opportunity for their students to gain national and internationally recognised qualifications. Specific curriculum statements and associated key competencies such as thinking skills, use of language, symbols, jargon and values are often so broad that they can rarely be fully met. The curriculum challenge for GL and GS and environmentalism is to enable students to learn, appreciate and comprehend the balance between reductionist science and its relationship to the bigger holistic picture of Science as a way of informing about Planet Earth, how it works and what people do to it.
7. Geological science is not environmental science, nor is it geoscience, but there is a clear need to develop science curricula that adequately includes and integrates the core educational values of what GL uniquely provides: Deep-Time and Earth history, scale, the fossil record, fieldwork, geological physical and chemical processes and visual spatialisation.

12.3 The GeoTSAT Instrument

The GeoTSAT instrument has been modified from that originally developed and validated by Kali (1990) and Kali and Orion (1996). GeoTSAT addresses research questions 2, 3 and 5. A paper and pen exercise, this instrument attempts to elicit student understanding (and misunderstanding) of relative geological time and structural spatialisation. Paper and pen exercises on spatialisation were augmented with the use of a plasticine model. Questions are based on the concepts of geological superposition, correlation, sequencing and paleoenvironments of rock formation. Structural questions attempt to elicit information about visual penetration ability and mental rotation. Conceptualising and applying understanding of Deep-Time is a challenge for all age groups. My favourite story for a conceptualisation of geologic time is that of the well known but quaint and out of date writings of Hendrik Willem Van Loon (1926). *"High up in the North in the land called Svithjod, there stands a rock. It is a hundred miles high and a hundred miles wide. Once every thousand years a little bird comes to this rock to sharpen its beak. When the rock has thus been worn away, then a single day of eternity will have gone by"*. What is good about this myth is that it connects with what people can comprehend: a thousand years. And it connects with peoples needs for stories. A million years stretches the mind but 4.6 billion years is beyond comprehension, especially when the length of a day continuously changes. The issues surrounding comprehension of time and the importance of teaching about scale are discussed in Chapter 6 and the results of different age groups to questions on visual spatialisation of geological structures, relative time and sequential histories are discussed in Chapter 11.

Without a cognitively meaningful concept of scale little of the natural world makes sense. According to Orion and Ault (2007) studies of how people develop their conceptions of geological time, systems and scale began only recently. These studies were either 'event based' (Marques, 1997; Noonan-Pulling, 1999; Trend, 1998, 2001a; Tretter, 2006a), or 'geocognitively based' (Ault, 1981; Dodick, 2003a; Ishikawa, 2006; Libarkin, 2004, 2005; Montangero, 1996). This thesis attempts both approaches and builds on the efforts of these workers. Geocognitive spatialisation is crucial for understanding geologic structures yet this appears to be one of the least developed and recognised aspects of a students key competencies (Black, 2005; Kastens, 2006; King, 2006).

Key findings and conclusions

1. The majority of respondents across all age groups are capable of correlating strata and therefore correctly conceptualising relative time. However, evidence discussed in Chapter 11 suggests that geocognitive ability to perceive relative time through correlated geological strata is underdeveloped. Furthermore, all age groups have similar difficulties in correlating geological strata especially when there are ‘missing’ layers or ‘additional’ layers. Respondents who are able to connect paleoenvironments with these ‘missing’ layers tend to be more successful at correlation of strata. Younger respondents tend to be superficial in their answers. This is shown by answers that use the relative positions of fossil icons rather than their stratigraphic positions.
2. Evidence discussed in Chapters 7 and 8 suggest that spatially identifying the connections between vertical change and horizontal change of rock type (sedimentary facies) is difficult for all cohorts. The concept of contemporaneous environmental change and its effect on the rock record (and the fossil record) is a challenge even for postgraduate geology students.
3. As respondent age increases, spatialisation ability for geological structures increases, but further research is needed to tease out the effects and influence of specialist geological training, gender difference and teaching techniques. Scanned examples shown in Appendix 7 show that the errors are similar for all age groups.
4. Similar mental rotation difficulties are seen across all age groups especially the ability to move from plan view to transverse or cross sectional view.
5. Results support those of Kali and Orion (1996), where the single most common difficulty is to visually penetrate and to move from a ‘surface’ view to a hidden ‘inside’ view. Gaining experiences in spatial visualisation is a major challenge for school curriculum developers.
6. Although understanding ‘what to do’ in questions on visual penetration ability is greatly improved with the use of a 3-D ‘hands on’ plasticine model,

the ability to visually penetrate remains difficult. Errors and misconceptions presented were common to all age groups including some postgraduate geology specialists. There is considerable scope for development and up scaling and using ‘hands on’ modelling for providing learning experiences for spatial development.

7. Linking a geological history to 2-D and 3-D (block diagram) rock exposure diagrams is difficult for all cohorts. Describing a geological history requires a correct sequence of events as well as knowing about and connecting geological environments with rock formation.

8. The sample of postgraduate geology students is able to perceive alternative sequential possibilities in geological history whereas many in all other cohorts do not. In other words these respondents can see ambiguity (Ault, 1998). An excellent example of a geological ambiguity is distinguishing between lithologic (rock) correlation and time correlation. Physical continuity of rock units is not the same thing as time correlation. Time correlative units are often determined by the fossil content, magnetic chronology or radiometric dating. Just having rocks of the same type does not make them the same age. It is important to note that geologically, rock types change vertically due to changing environments through time and that horizontal changes of sediment (and later rock type), occur at the same time or 4-D contemporaneously. This kind of interrelated complexity and indeed the need for clear written description is a major barrier (especially for today’s socially sophisticated and electronically oriented students) to learning not only the geological sciences but also the biological sciences.

12.4 The GeoVAT Instrument

Geological science informs and constrains timing and environment for the evolution of life. The GeoVAT instrument is derived and modified from Dodick & Orion (2003a) and Trend (2001a) and addresses research questions 3 and 5. It takes a geocognitive paleogeologic approach as well as an ‘event’ based approach to eliciting the conceptualisation of a cross-age set of cohorts (See Chapter 5). This instrument asks about ideas on the nature and **relative time** origins of fossils and the fossil record (event based) as well as asking about the meaning of fossils as indicators of geologic environments and evolution (geocognitive). The relative time aspects of this instrument correspond to the diachronic schema of Montangero (1996) as outlined and discussed in Chapter 6. One question (Section B Q2a) triangulates with the GeoTSAT instrument with regard to mental rotation by requiring a transverse (cross) section to be drawn from plan view. This also requires a degree of visual penetration ability. Chapter 10 outlines the findings for the GeoVAT instrument as well as investigating key issues of evolution in constantly changing curricula. New Zealand is used as a case study for the status of teaching evolution in a western secondary school curriculum.

Key findings and conclusions

1. Having a more sophisticated perception of the scale of geologic time is not only the unique contribution that geological science makes to an understanding of our planet, but is crucial to a better understanding of the evolution of life. The links between evolution and geological time have been vastly and well documented (Alles, 2001; Alters, 2002; Catley, 2005, 2009; Cummins, 1994; Dagher, 2005; Deniz, 2007; Dodick, 2007, 2003b; Griffith, 2004; Jensen, 1995; O'Brien, 2000).
2. Findings to the GeoVAT instrument (Chapter 10 and Appendix 6) indicate that all cohorts across an age range of approximately 40 years do know what fossils are but that even in this small study sample, the creationist pseudoscientists are represented and are conspicuous by their dogmatism. Indeed, recent work by Bickmore, Thompson, Grandy and Tomlin (2009) point out the conceptual tensions between a learners desire for ‘certainty’ and the presentation of the nature of science as being tentative. The misconception being that science “proves the truth” rather than being uncertain or ‘open ended’. The links between scientific testability and the abstract concept of ‘certainty’ is difficult to teach to teenagers and undergraduates. Understanding the fossil record and its links to unravelling the history of life requires a measure of understanding about the nature of science. Montgomery (2009) shows clearly the importance of focussing on the scientific aspects of scientific controversies rather than the social impact aspects. Using relevant aspects of the history of our understanding about the

fossil record may be useful in developing a better understanding of the interconnectedness between evolution, fossils and geological science. What actually is a scientific controversy? Clearly, using pseudoscience as a counterpoint to scientific theory is illogical. In the New Zealand school curriculum there is an internal assessment standard on scientific 'controversies' but far too often, selected 'controversies' are not only misconceived as 'social controversies' (an issue for socio-scientific issues), but they also do not investigate both sides of the **science** involved. The evolution of life is not a scientific controversy.

3. The fact that a majority of respondents think that Charles Darwin was the originator of the theory of evolution (Chapter 10 and Appendix 6) speaks volumes for the lack of teaching (and poor representation in curricula statements), about the history of science and the people who made it. Few teachers are specialists in the history of science in much the same way that most teachers of science are not specialists of geological science or astronomy.
4. The majority of respondents in this study are aware that a scientific theory is not just a guess but is a naturalistic explanation of observable phenomena based on testable evidence and with the prospect of abandoning untenable explanations. There is, however, a general lack of awareness of the notion of punctuationism as an additional explanation for evolutionary processes found within the fossil record. Respondents do know what fossils are but lack the detail of geobiological interpretation. Similarly, despite genetics and in particular, molecular genetics being the dominant current concepts of school biology (Chapter 10 and Appendix 6); there is poor teaching and learning linkage between these disciplines and biological evolution. This can be traced to historically poor curriculum linkages between geological science and biological science (Cummins, 1994; Deniz, 2007; Dodick, 2007; Dodick, 2005; Rutledge, 2000; Sinatra, 2003). Formal training in Biology tends to be with the living world rather than the extinct. In the New Zealand case study of evolution and biology in the curriculum, despite there being around a national total of 42,418 students (www.educationcounts. govt.nz) studying at Year 13 (level 3 NCEA) in July 2008, only around 4500 students (11%) gained qualification credits in assessed standards on human evolution,

speciation and evolution in general at NCEA level 3. Level 3 is the final year at high school prior to university level for New Zealand students. So, in fact, the vast majority of students (89%) leave school never knowing about the key issues, scientific information and mechanisms of biological evolution. Even fewer have an opportunity to appreciate the connections between biological evolution, the fossil record and geological time because of poor curriculum linkage and lack of teacher training infra structures at both secondary and tertiary levels. The details and status of student performance in biological evolution related assessment standards are presented in Chapter 9. Of the twelve assessment standards related to evolution, the vast majority of students gain their credits from only three: one at Year 12 Biology and two at Year 13 Biology. The percentage of passes increases from an average of 25% at decile 1, to 70% at decile 10 increases with independent private schools achieving 70% passes. Deciles are a socio-economic indicator.

5. There are typically, poor teaching and learning connections between micro and macro evolutionary concepts and processes (Dodick & Orion, 2005; Hallden, 1998; Mayr, 2001). The study of paleoecology, paleoenvironments and paleontology within biology curricula is a missing link in this conceptual connection and future subject and curriculum reforms should reflect this connection in much greater detail. In the recent (2007-2011) reforms and implementation of the New Zealand curriculum for example, evolution is clearly recognised as a guiding theme in science literacy throughout all the schooling years, but does very poorly when connecting geological science with biological science. Having a better conceptualisation of biological evolution depends on a better conceptual status of geological time and environments. Results to questions on perception of scale (Chapter 6) suggest that as age (experiences and brain development) increases the perception of time becomes more sophisticated and conceptualisation of the linkages between time and evolution begin to crystallise. Building on the work of Tretter et al. (2006a) and Trend (1998; 2000; 2001) evidence from a small illustrative study of perceptions of various scales such as time, mass, number and size suggest respondents from all age groups first look for experienced scale-boundaries (usually their own bodies) and then refine their perceptions.

As the scale goes beyond their experiences there is a tendency to 'lump' values into large single categories.

6. It is unfortunate that science curricula typically do not promote a broader understanding of scalar dimensions and their connections with most disciplines of learning. The unique contributions of geological science to science literacy should not be lost in future reforms. As Tretter, Jones & Minogue (2006b) point out,

> *"The use of unifying themes that span the various branches of science is recommended to enhance curricular coherence in science instruction. Conceptions of spatial scale are one such unifying theme". (Tretter et al. (2006b), p.1061).*

It often appears that curricula reforms refine, reduce and rearrange rather than inclusively develop a well resourced pedagogy for scalar dimensions of time, distance and spatialisation. There is much to be done and geological science provides a unique vehicle for developing student understanding of scale perceptions for a better scientific literacy.

12.5 Limitations

1. A key intention of this study was to provide a snapshot across a wide age range and different countries of origin, of conceptualisations held about aspects of geological science. It does not statistically represent a wider community and making generalisations would be invalid and unreliable. The specific and general issues of reliability and validity of data collection for questionnaires are addressed in Chapter 5. However, responses received provide useful insights into the conceptual status of a wide age range of respondents to aspects of visual spatialisation, interpretations of the fossil record, understandings about biological evolution and geological time.
2. All research efforts have limitations of time and resources. This thesis is no exception. Gaining access to schools and tertiary institutes for a large scale quantitative study is beyond the capacity of the researcher. Being the school

co-ordinator for the PISA surveys and aware of the vast resources of the OECD for surveying 15 year old students reinforces the difficulty of achieving sufficient response returns just from one school let alone from 60 different countries!

3. Sample size is always an issue unless exhaustive trialling clearly establishes the sampling size boundaries needed for quantitative representation. This is beyond the scope of this study and the researcher. In this thesis data collection instruments, the number and types of response to questions are quite limited and there are sufficient responses that cover most potential responses. As outlined in Chapter 5, in questionnaires there is little control over who answers what, and in the end, the data collected is what it is. Perfection does not exist.
4. Interpretations of responses are all the researchers, so internal bias is a permanent part of the story. Oversimplification, misinterpretation and inaccuracies are ever present but it is expected that replication by other workers will add to and correct the inaccuracies in an effort to get closer to the realities of the conceptual status and spatial perceptions of future respondents.
5. Little analysis of gender issues were completed as this introduced another layer of complexity. Future work could focus more specifically on gender issues especially for spatialisation and VPA development and development of scalar comprehension.

In summary, this mixed method study’s questionnaires are limited by small sample size, are not statistically representative, suffer from researcher bias and are in parts, in danger of being an oversimplification. In mitigation, internal triangulation (with minimal respondent interviewing) and use of previously validated material and publicly available data bring together a snapshot of conceptualisation and perceptions of key geological phenomena and their relationships to science curricula, teaching and learning.

12.6 Implications for Teaching and Learning

1. There is a need to develop and implement stronger and assessable curriculum connections between geological, paleontological and biological science.
2. The geosciences and geological science specifically, struggle for existence in most science and geography courses globally (Trend, 2009). There is a need to develop an infrastructure of support with modern resources within teacher training institutions, schools and universities.
3. Most secondary school teachers are not trained in geological or geoscience and exhibit the same conceptual difficulties as their students. Their learning experiences have been much the same as their students and as a result, many schools simply do not teach the earth sciences and especially geological science. In-service training is the vital link between a geologically informed curriculum, teacher training and establishment of geological science as a vital discipline for a citizen's adequate science literacy (Trend, 2009).
4. Geological science is not Earth Systems Science nor is it Environmental Science. It is the glue that holds the reductionist science hierarchy together. By providing adequate tuition time by trained and qualified geoscientists in developing concepts of scales of time and size, a better conceptualisation of evolution and earth history can be achieved. This requires integration of fieldwork, use of information technology (IT) and specially developed software for improving spatialisation skills into a schools culture of learning. Secondary school students at 13 years of age have naïve views of the natural world but they are cognitively primed for development of conceptualisation about how the Earth works, what it is made of and how it has evolved through time. Curricula development lets them down.
5. Conceptual change research developed over the last 30 years (Ausubel, 1968; Duit, 1999; Duit & Treagust, 2003; Treagust & Duit, 2008; Posner et al, 1982; Vosniadou 1992) point out the complexities of achieving and maintaining conceptual change. A challenge for educational researchers is to find more effective ways for not only classroom teachers but also policy makers to change their conceptual status for the teaching and learning of geological science. Clearly, these stakeholders are, in classical Posnerian terms, not affectively dissatisfied enough to want to change the way they

think about the Earth as a dynamic and fragile planet, the evolution of life within it and the connections of geological science to all other fields of scientific endeavour.

12.7 Finale

The study of geological education has been a life long pursuit. Ever since hearing the word 'Geology' in New Zealand in Year 11 (aged 15 years), I was fascinated by what makes this planet tick and how the life on it and in it could be scientifically explained. Geoscience in New Zealand schools in the early 1960's was dominated by physical geography in the form of geomorphology (today only about 35,000 students nationally in NZ are enrolled at NCEA level 1 Geography) with lots of photographs and diagrams of landforms found in 'the textbook' (Cotton, 1964) that could be easily related to by teenagers. This 'triggered' an interest in questioning how the surface of the Earth evolved (See Chapter 4, p.115 for notes about self determination theory) and led eventually to other questions about the how and whys of geological science and its specialist branches. After nearly a decade of teaching I finally wrote an article (Vallender, 1981) suggesting that geological science and appropriate fieldwork (not specifically physical geography or even physical geology) was a vital part of a functional scientific literacy and should be more thoroughly included in science curricula and be assessable in the same way as physics, chemistry and biology. This eventually happened (partially however, because the credits gained in examination success were not the same as the other traditional sciences) in the 1994 national curriculum revisions and movement to a standards based assessment system but only to be slowly eroded away by 2010. This is a globally familiar curriculum story.

Most students are intrinsically curious about our planet's history; they want to know what it is made of, how it got there and how it works. They also want to find out more about what happens beneath their feet and the origin of hills, mountains and valleys. Most high school students are cognitively primed for conceptual development but the pedagogy and infra structures for teaching and learning geological science in particular are not adequate globally or locally. The challenge is to find ways of more fully integrating geological science into curricula and developing a coherent conceptual change model of teaching and learning. And one that future citizens have a more sophisticated conceptual awareness of scientific theories of evolution, the significance of the fossil record, how plate tectonics works and how earth systems interact. This cannot be done as an ‘add on’ or ‘plug in’. Nor can it be achieved by integration alone. It is too big for this.

People should be able to make informed decisions about broader geoscience issues based on accurate conceptions of scientific evidence (especially geological processes as this provides the evidence that underpins the mechanisms of natural hazards and an understanding of Earth history) rather than naïve misconceptions, myths and legends. Geological science is uniquely suited to developing spatialisation skills and makes linkage with all other sciences through geological time. The Earth will still be here in 2 billion years time and what a geological story it will tell. Effecting conceptual change in individual world views takes time but it is hoped that this thesis not only supports prior research evidence but has also added new pieces to the jigsaw of geological education within secondary school and tertiary curricula and provided a stage for developing conceptual change teaching models based on a picture of constructivism, student conceptual status and geocognition. Time will tell.

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APPENDIX 1

Curtin
UNIVERSITY OF TECHNOLOGY

Ph. … ...…..
Fax. ………
Email. ge.vallender@

Woodham Drive
Ashburton

12 October 2004

The Principal

Dear

I have recently been in contact with your head of science faculty Mr Alan Munro. Mr Munro has agreed to allow his science students to act as a trial school for the pilot development of research instruments as part of my extramural doctoral research programme at the Science and Mathematics Education Centre (SMEC) at Curtin University in Perth. I teach at Ashburton College.

The research involves the distribution of questionnaires to each year level of students studying science so that information can be gathered on several aspects of student conceptualisations of the fossil record and geological time in an Earth Science context. This N.Z. science strand is of considerable international educational research interest and has its own intrinsic value. Along with a questionnaire designed to gather information about the science curriculum taught in your school there are also questions for students designed to establish demographic data for statistical analysis purposes.

Student participation is voluntary and no names are required. Any student's wish not to be involved will be respected. Individuals will not be identifiable in thesis work or in any educational conferences or scholarly journals.

The purpose of this letter is to inform you and to request your permission for your schools participation. It is estimated that the questionnaires would take a class up to 45 minutes (or allowance of one period) to complete. If you have any difficulties with the request, or would like further information concerning this research study, please contact me at the address above. I am very aware of the time these research questionnaires take, and I thank you for your support.

Yours faithfully,

Glenn Vallender
(Doctoral Student)

Curtin
UNIVERSITY OF TECHNOLOGY

Ph. …………….
Fax. ……………
Email. ge.vallender@

Woodham Drive
Ashburton

12 October 2004

Dear Parents and Guardians,

The purpose of this letter is to inform you about my visits to your child's Science class and to request your permission to interview your child.

I am a doctoral student in the Science and Maths Education Centre at the Curtin University of Technology in Perth, Western Australia, but I work and live in Ashburton, New Zealand. My research is concerned with the way in which students and adults develop their concepts of geological time and the fossil record, and the way in which different schools and tertiary institutions in different countries present their instruction.

I have permission from the principal, Mr/Mrs/Dr XXXX and your child's science teacher and head of science to enter the school to carry out properly conducted interviews and questionnaires with a number of students from each year level. Interviews will take between ten and twenty minutes and will not interfere with any teaching programme. I have found in the past that these discussions can be helpful as well as informative.

Student participation for a discussion interview is entirely voluntary and involves answering further questions to tease out the details of their questionnaire responses, and to provide a cross reference for the collected data. Any student's wish not to be involved will be respected. No individual will be identifiable and they will be reported anonymously in my thesis and in any subsequent educational conference or scholarly journal. Confidentiality is important and assured. Information gathered is totally independent of any school work and has no bearing on any assessment.

If you have any questions or concerns, please feel free to contact me at the above address. If you can't contact me personally, please leave a message and I will return your call. Thank you for your support.

Yours faithfully,

Glenn Vallender
(Doctoral Student)

APPENDIX 2

Geological Time Questionnaire

Instructions:
These questions are designed to gather information about how students of different ages and from different countries understand aspects of geological time.This is to help teachers improve the way topics can be taught. **Your name is not required and this is not a test which counts towards any certificates or awards.** Your answers to 'about yourself' will help make sense of some of the responses that you make. The codes on these sheets are for administrative reasons only. Your answers are totally cofidential and no individual will be identifiable in any future publication.

Note that completion of this questionnaire assumes you are a willing participant.

Please write your answers in the spaces provided.

About Yourself

1. How old are you? Years ……………. months ………………..

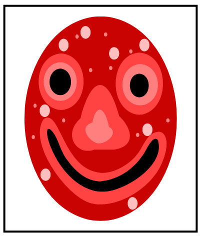
2. Are you male or female? ……………………………….

3. What country were you born in? ……………………………………..

4. What ethnic group do you identify with? ………………………….

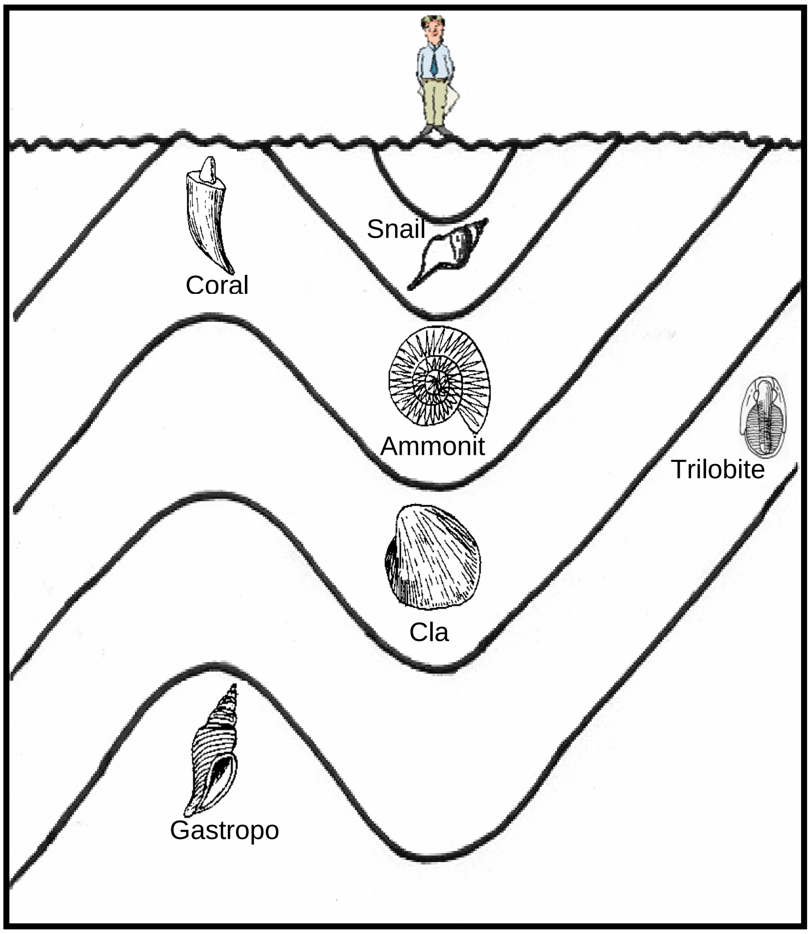
5. What is or was your favourite school subject? …………………….

6. When did you last study any geology (earth science)? …………………….



Your Ideas About Fossils and Time.

1. *The person in the diagram below is standing on top of layers of marine sedimentary rock containing fossils. Imagine you are looking at an exposed sea cliff face.*



Name of fossil in age order (1 is oldest)

1. ………..……

2. ……………..…

3. ……………..…

4. …………...

6. …………...

(a) *In the box above, place the fossils in order from the oldest fossil to the youngest fossil.*

(Clue: marine sedimentary rock is originally deposited in horizontal layers and the layers have not been tipped upside down).

(b) *Name the fossils which are the same age?*

…………………………………………………………………………………………………

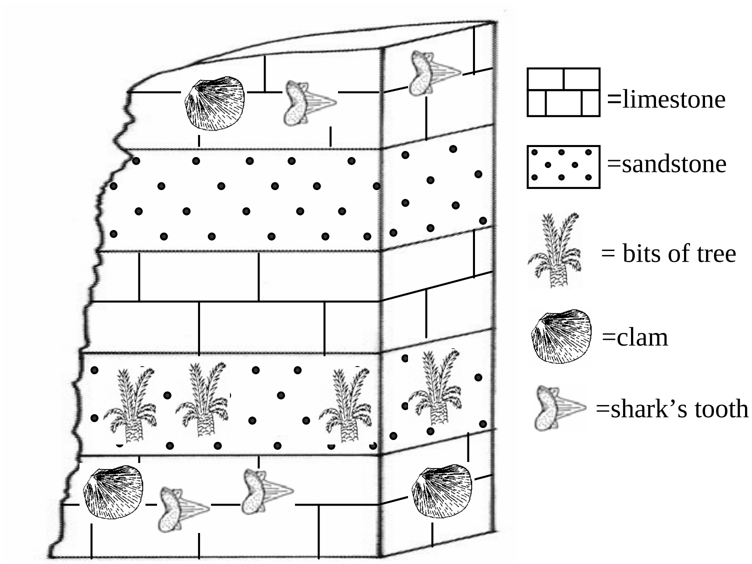
…………………………………………………………………………………………………

(c) *In the picture for question 1 above, describe how this rock exposure might have been formed.*

…………………………………………………………………………………………………

…………………………………………………………………………………………………

2. *The illustration below represents a sequence of rock layers.*

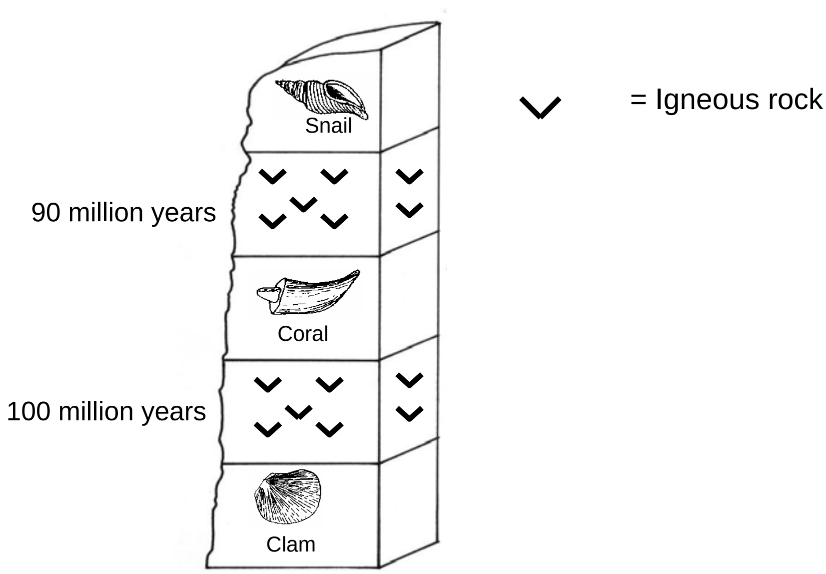


Describe the geological events and processes which might have created this sequence of layers based on their order of formation. The layers have not been tipped upside down.

…………………………………………………………………………………………..…

…………………………………………………………………………………………...

3. *The following picture represents a rock exposure that contains three types of fossil animal (snail, coral and clam). Two layers of igneous rock lie between the layers containing the fossils. The ages of the igneous rock layers have been accurately dated in the laboratory by scientists and recorded beside the layers.*

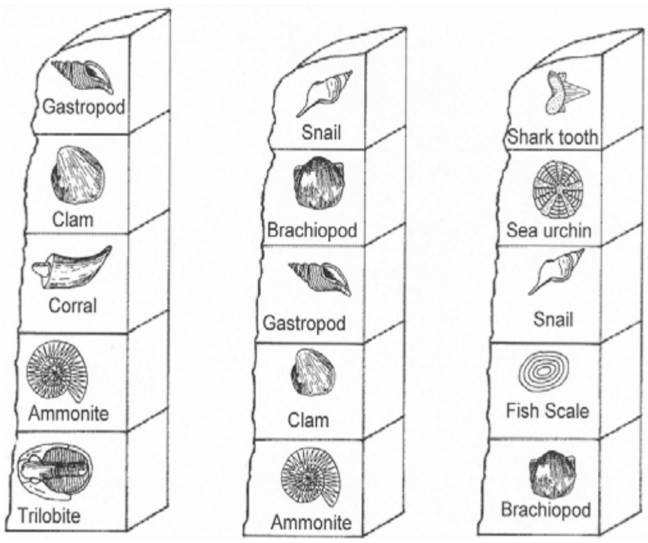


What is the age (in years) of the three different fossils (snail, coral and clam).

Ages are: a) snail ……………..… b) coral ………………… c) clam …………………

4. *The illustration below represents three different rock exposures containing fossils.*

Write down the name of the fossils in order of age, from oldest to youngest

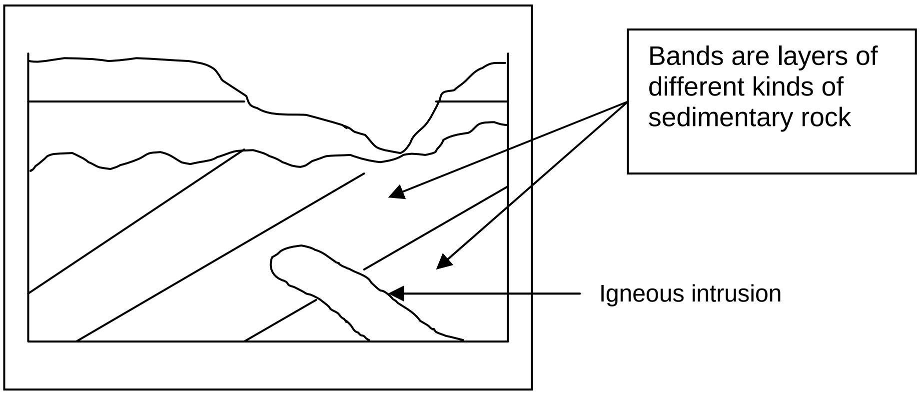


Youngest ↑

1. ……………….
2 ……………….
3 ……………….
4……………….
5……………….
6……………….
7……………….
8……………….
9………………
10 ……………..

Oldest

5. *The following diagram illustrates a geological cross section. List, in time order, the events that might have happened to cause this situation.*



Event one ……………………………………………………………………………………….

Event two ……………………………………………………………………………………….

Event three ……………………………………………………………………………………

Event four ……………………………………………………………………………………

Event five ………………………………………………………………………………………

Event six ………………………………………………………………………………………

6. Look at the two letters below and then draw what you think they would look like when they are upside down and back to front!

e G

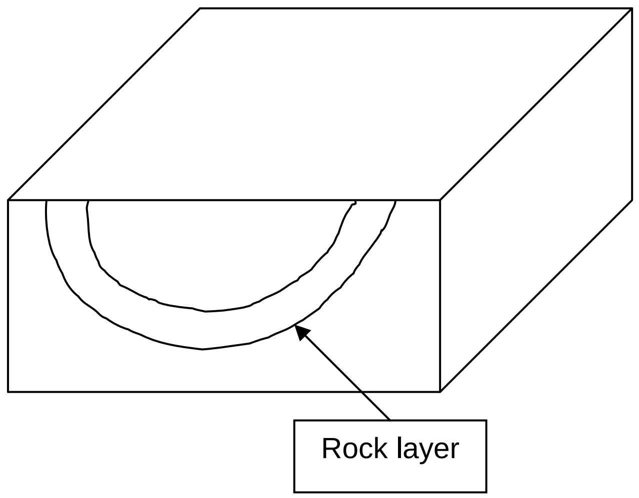
(a) **Upside down**

e G

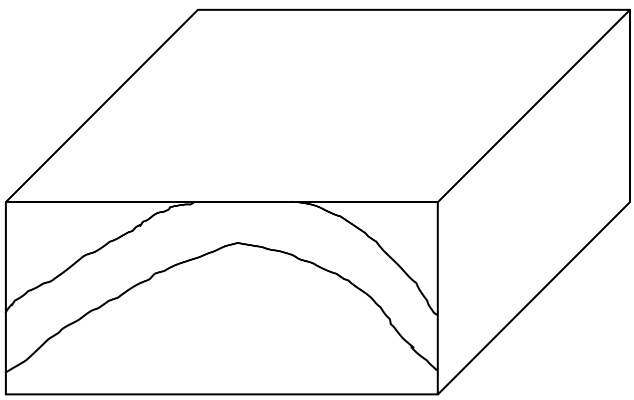
(b) **Back to front**

7. *The following block diagrams illustrate incomplete geological structures. Draw in where you think the rock layer continues on the side and/or top of the blocks.*

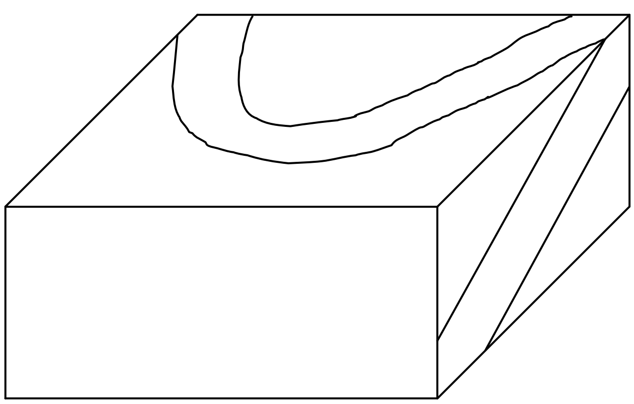
(a)



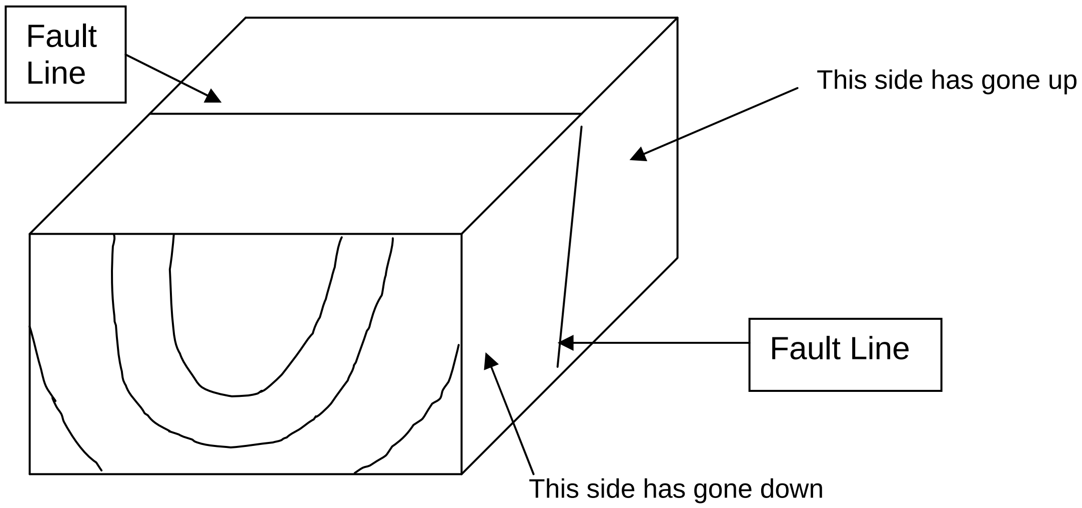
(b)



(c)

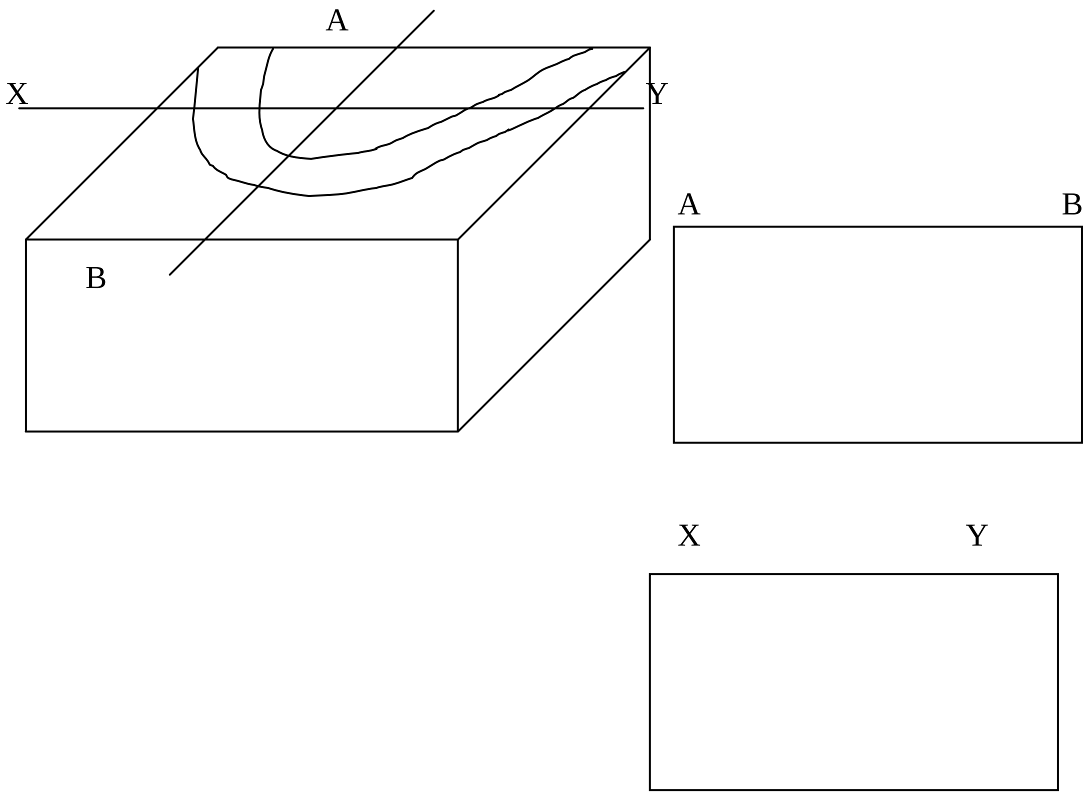


(d) *Sometimes rock layers can be broken and offset by faults. Draw on the diagram what you think the rock layer will look like on the top face and side face of this block diagram.*



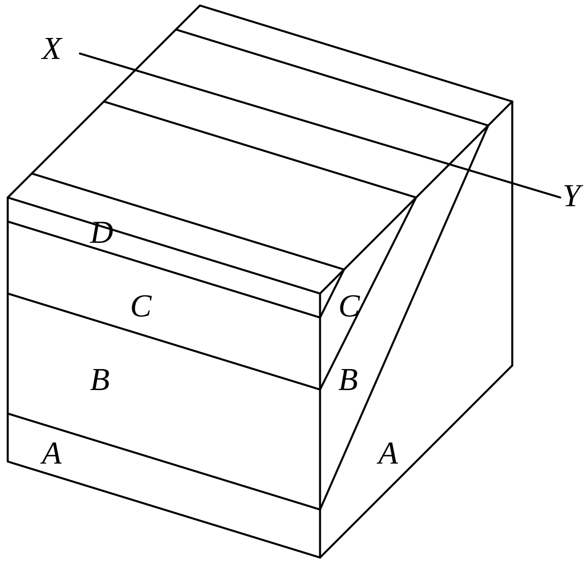
7 (a) *This diagram is the same as 6 (c). Imagine that this block is cut vertically down and split apart along the line from A to B. Draw a cross section of what you think the layers are like along this line when the two halves are separated.*

Draw sections in the boxes below



7 (b) *This block diagram shows rock layers represented by A, B, C and D. Draw in the box, what you think the layers look like when the block is cut vertically downwards along X and Y.*

Draw lines in box



X *Y*

7 (c) The earth is like a ball made from several internal layers. In the box below, draw what you think the inside of the earth would look like if it was made of three layers and you cut it through the middle (cross-section).

Cross-section

Thank you for your help. Your honest answers will help us better understand how we go about thinking and solving different kinds of geological problems.

APPENDIX 3

New Zealand:

Chapter Nine: A Case Study of Geological Science in a National Curriculum

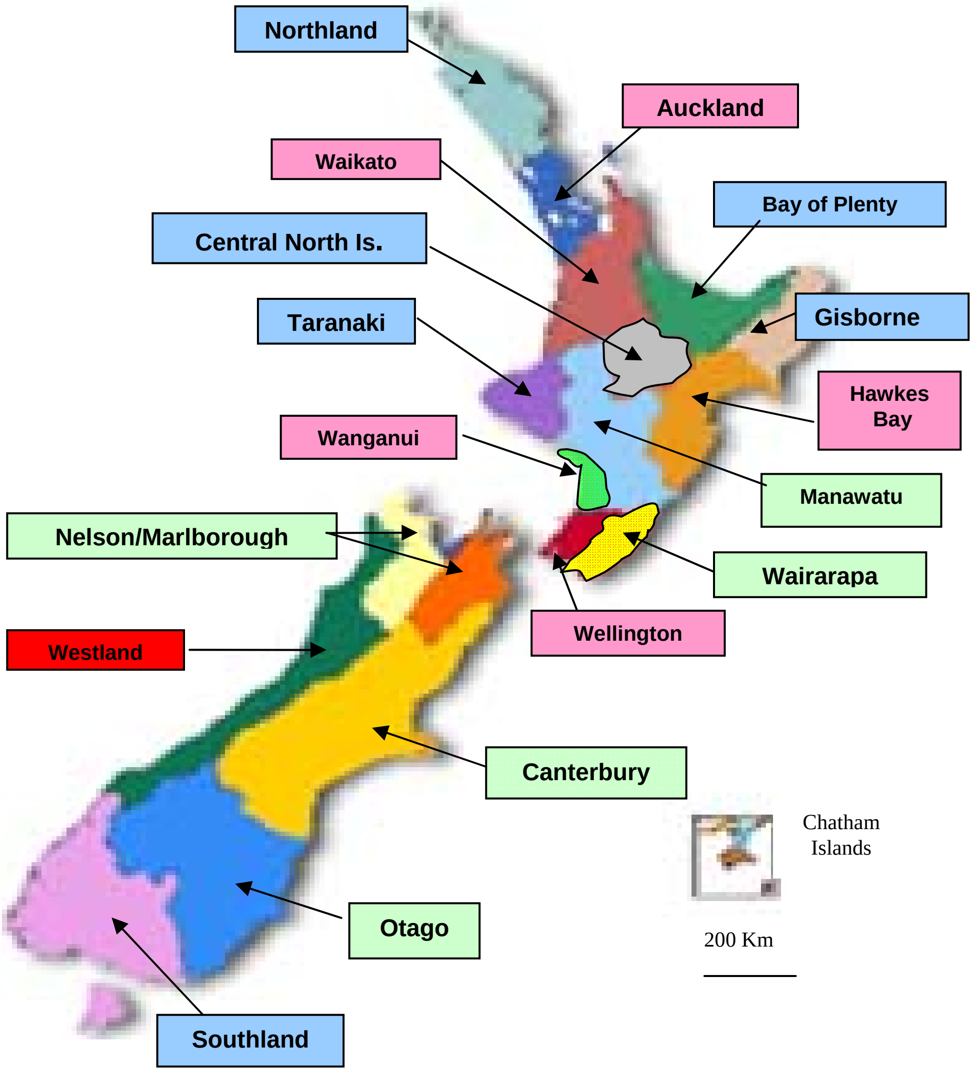


Figure 9.5. New Zealand School Regions

Assessment Opportunities for Geology and Evolution in the New Zealand National Qualifications Framework (NQF) 2002 -2010.

Note that as from 2010 some of these standards will have been aligned with changes in the 2007 national curriculum reforms. The geoscience strand has undergone significant change to encompass an environmental/earth systems philosophy and a decrease in geological science content. The unit standards detailed here will become achievement standards and also aligned with the national science curriculum changes. This is detailed in the postscript in Chapter 9.

Key to acronyms used in standard descriptor tables:

US = unit standard. AS = achievement standard. Int. = internally assessed

Ext. = externally assessed. NQF = National Qualifications Framework

Cr. = credit value.

Note:

1. For each of the assessment standards shown below, specific details of content range and criteria are available on the NZQA website
2. Internal assessment means that moderated assessment is carried out within the school and not by a national exam.
3. The following tables specify titles only for assessment of fossils, geological time and evolution.

Biology NQF Level 4 (Year 14 = age 18/19)

Standard	Description	Credit value	Mode
US 8105	Explain the principles of evolution and biogeography.	4Cr	Int.
Scholarship	Derived from level 3 (year 13) NCEA.	0Cr	Ext

Biology NQF Level 3 (Year 13 = age 17/18)

US 6317	Explain the process of speciation	4Cr	Int.
US 6318	Interpret scientific evidence for human evolution.	4Cr	Int.
US 6321	Investigate and describe scientific views of human biological evolution.	3Cr	Int.

AS 90717	**Describe patterns of evolution.**	**3Cr**	**Ext.**
AS 90719	**Describe trends in human biological and cultural evolution.**	**3Cr**	**Ext.**

Biology NQF Level 2 (Year 12 = age 16/17)

US 6311	Explain reasons for the special characteristics of NZ's flora and fauna.	3Cr	Int.
AS 90459	**Describe genetic variation and change.**	**3Cr**	**E**

Biology NQF Level 1 (Year 11 = age 15/16)

N	**No opportunities** at this level for topics about fossils, evolution and geological time.	N	N

Science NQF Level 4

US 8140	Investigate, interpret and report on geological features, landforms and active processes of a site.	5Cr	Int
US 8145	Read geological maps and interpret geological history.	4Cr	Int.
US 8147	Demonstrate a knowledge of the interior of the Earth and geophysical fields	4Cr	Int.
US 8152	Collect water samples for analysis	4Cr	Int.
Scholarship	No opportunities in these topics.		

Science NQF Level 3

US 21614	Describe the geological history of an area in the Southwest Pacific.	3Cr	Int.
US 6365	Demonstrate knowledge of geological hazards	3Cr	Int.
US 6364	Use plate tectonics to explain distribution of major NZ and Southwest Pacific geological features.	4Cr	Int.
US 8153	Explain factors affecting a water resource and its management, and plot and interpret hydrographs.	4Cr	Int.
AS 90731	Describe geological processes affecting New Zealand.	5Cr	Ext.

Science NQF Level 2

US 6362	Demonstrate an understanding of fossils.	3Cr	Int
US 6360	Identify geological features from recorded visual information.	2Cr	Int.
US 6361	Investigate and report on the geology in an area.	4Cr	Int.
AS 90767	Describe NZ’s geological history.	3Cr	Ext
AS 90772	**Describe the factors and processes involved in the evolution of NZ plants and animals.**	**4Cr**	**Ext**

Science NQF Level 1

US 6356	Report on a geological resource in New Zealand.	3Cr	Int.
US 6357	Identify common minerals and rocks.	3Cr	Int
US 6358	Describe the formation of major rock types and describe the rock cycle.	3Cr	Int
AS 90190	**Describe aspects of Geology. (30 minute exam)**	**3Cr**	**Ex**

NZ Assoc. of Science Educators Certificate (NZASE) derived from Curriculum Levels 4 and 5, NCEA Level 1

US 18981	Demonstrate Knowledge of Weather	2Cr	Int
US 18982	Demonstrate Knowledge of Earth Science	2Cr	Int
US 18989	Demonstrate Knowledge of Earth and Space	2Cr	Int

Table 9.6. Earth Systems principles (Mayer 1997).

Understanding	Guiding Principle
Understanding 1	Earth is unique, a planet of rare beauty and great value
Understanding 2	Human activities, collective and individual, conscious and inadvertent, affect planet Earth.
Understanding 3	The development of scientific thinking and technology increases our ability to understand and utilise Earth and space.
Understanding 4:	The Earth system is composed of interacting subsystems of water, rock, ice, air, and life.
Understanding 5	Planet Earth is more than 4 billion years old and its subsystems are continually evolving.
Understanding 6	Earth is a small subsystem of a solar system within the vast and ancient universe.
Understanding 7	There are many people with careers that involve study of Earth's origin, processes, and evolution" (Mayer, 1997, p. 5)

Where do Geology Qualification Credits Currently Come From?

Given that comparing achievement needs to account for equal deciles it is also useful to compare regions of similar deciles and the standards that students are gaining credit from in learning Geology.

Regional clusters A – D shown in Figure 9.12 were derived from multivariate cluster analysis using a minimum variance agglomerative technique (Kovach, 1998) of the percentage of each decile per school within each administrative region. Minimum variance clustering focuses on determining by 'sum of squared distances' the least amount of variation in each cluster. These clustered regions have similar school decile profiles. For each regional cluster, the percentage of results which gained credits in Geology were graphed against the assessment standards which generate credit opportunities. For each regional cluster, the percentage of results which gained credits in Geology were then graphed against the assessment standards which generated credit opportunities for NCEA levels 1 to 3 (Figure 9.13). The dendrogram (Figure 9.12) shows four clear clusters of schools with similar decile profiles, three of which are rooted at similar distances. Westland region is unique by being rooted at a significantly greater distance suggesting a significant regional difference in socio-economic circumstances. Are results related to socio-economic factors and regions? Further analysis and research (especially including regional ethnicity distributions and other socio-economic indicators such as occupations and household incomes) is needed to independently validate these clusters.

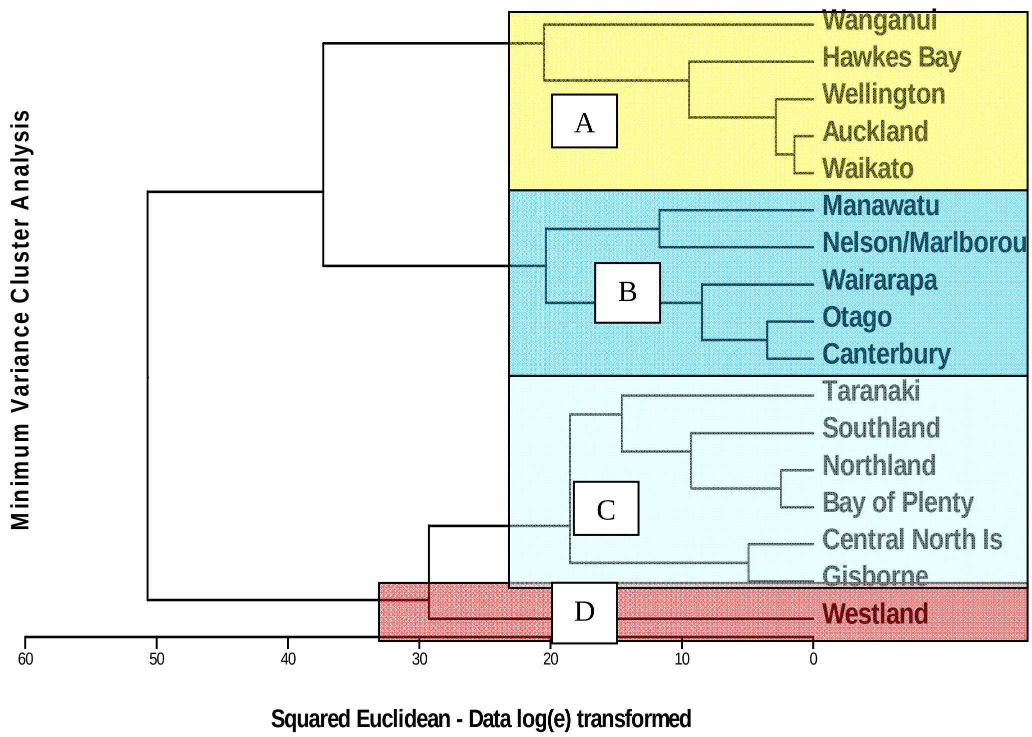
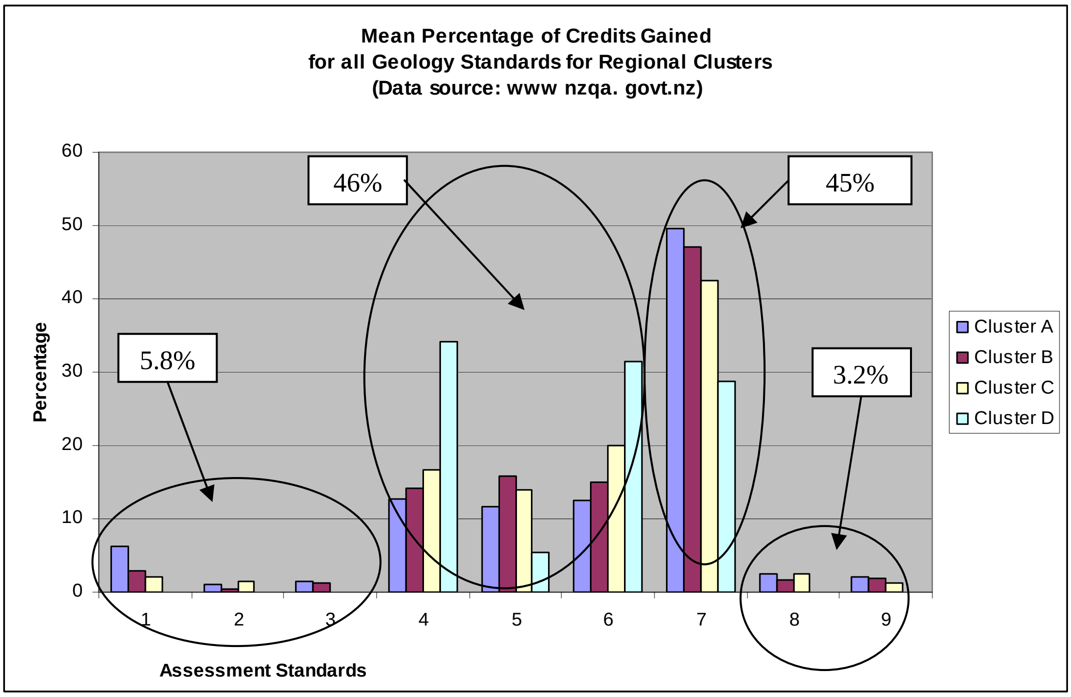


Figure 9.12. Dendrogram of regional clusters of school deciles.



Key to Standards	Regional Clusters with Similar Decile Profiles
1 = US L3 CL8 2 = US L2 CL7 3 = US L1 CL6 4 = US 18981 L1 CL4/5 5 = US 18982 L1 CL4/5 6 = US 18989 L1 CL4/5 7 = AS 90190 L1 CL6 8 = AS L2 CL7 9 = AS L3 CL8 US = Unit standard CL = Curriculum level L = NCEA level 18981 = 'Weather' 18982 = 'Geology' 18989 = 'Earth in Space'	**Cluster A** = Wanganui, Hawkes Bay, Wellington, Auckland, Waikato. **Cluster B** = Manawatu, Nelson/Marlborough, Wairarapa, Otago, Canterbury. **Cluster C** = Taranaki, Southland, Northland, Bay of Plenty, Central North Is, Gisborne. **'Cluster' D** = Westland. Clusters are derived from 'Minimum variance' multivariate cluster analysis based on the percentage of schools per decile. N = 434 schools

Figure 9.13. Regional clusters and Geology credits gained.

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Interpretations

Relationships between decile ratings, school regions (Figure 9.5) and where credits are gained for the assessment standards of Geology in the NZ curriculum are shown in Figure 9.14. In effect this figure shows what schools teach and what students do for the gaining of credits in Geology, within statistically clustered geographic regions of similar decile profiles.

1. The region of Westland has a small number of secondary schools (8) in a large and remote geographic area (where earthquakes are common) with 25% of its schools at deciles 1 to 3 (and over 60% at deciles 1-4) (Figure 9.14). Westland (cluster D, Figure 9.13) not only has the lowest percentage of results gaining credit for achievement standard 90190 (*"Aspects of Geology")*, but the also the highest mean percentage of results gaining credit for curriculum levels 4/5 NZASE (unit standards 18981and 18982). It is notable also for the lowest percentage of credits from NZASE unit standard 18989 (*"Earth in Space")*, an astronomy unit. These facts confirm the common relationship between achievement and decile rating.

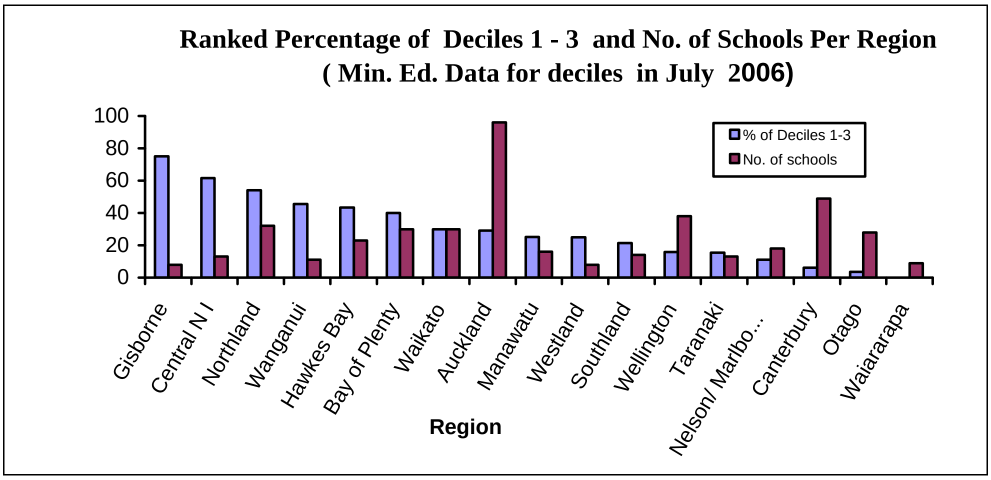
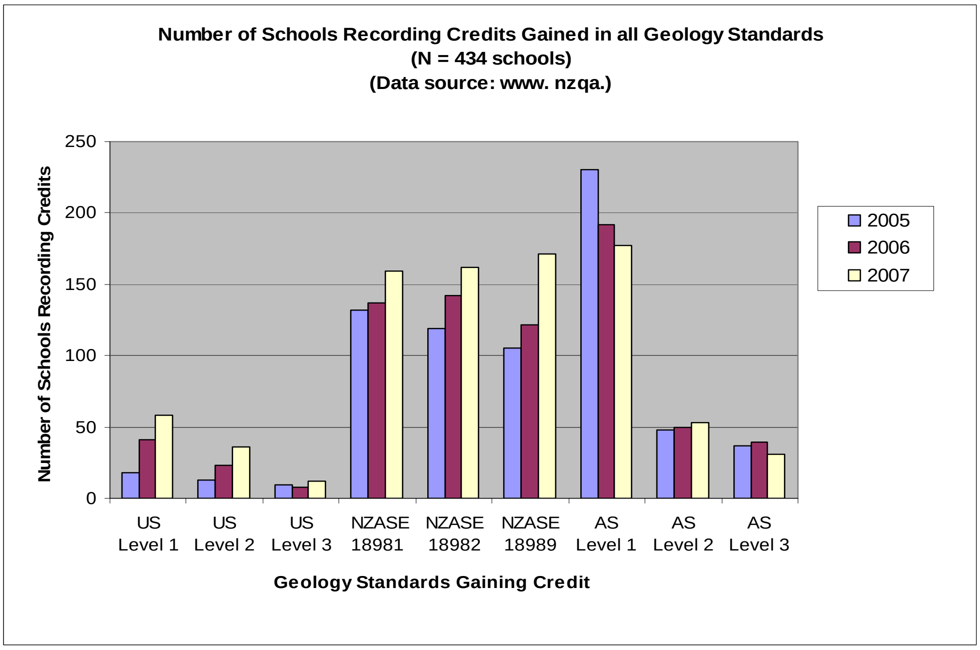


Figure 9.14. Percentage of low decile schools and school numbers per region.

2. NCEA Levels 1 to 3 unit standards makes up a very small percentage of the total contributions to total available credits in geoscience. Over 95% of schools in all regions and across all deciles simply do not teach these unit standards as shown in Figure 9.12 but 53% of all secondary schools offer level 1 AS 90190. The main reason for this is that when the 1993 Science curriculum was introduced, geological

science was innovatively accepted as an equal partner to physics, chemistry and biology by most schools despite sharing five credits with astronomy. As a result, schools were obliged to teach geological science. As can be seen from Figure 9.15 there has been an increase in the number of schools offering unit standards at each NCEA level and a decrease in the number of schools offering achievement standards at level 1 in geological science, but an increase in schools offering NZASE courses. Schools offering level 2 geological science standards are stable but declining at level 3. It is unknown how many schools offer geology standards but has had no students gaining credits. It would be rare for a whole cohort at a school to fail examinations.



NZASE 18981 = “*Demonstrate Basic Knowledge of Weather*”
NZASE 18982 = “*Demonstrate Knowledge of Earth Science*”
NZASE 18989 = “*Demonstrate Knowledge of Earth and Space*”

Figure 9.15. Number of secondary schools teaching geoscience as represented by results gaining credit (Student passes).

Achievement standards and unit standards are perceived as appropriate for the majority of Year 11 students who intend to continue their academic studies, although it is likely that unit standards are perceived by secondary teachers to be of lower quality than achievement standards (Hipkins, 2005; Zepke, 2005). Students gaining credits in NZASE certificate courses such as US 18982 gain credits for NCEA level one but these courses are non-advancing to levels two and three because they are derived from lower curriculum levels and designed for lower ability students. It also reflects the fact that Year 11 studies have been historically entrenched in the New Zealand psyche as the single most important (and the first) qualification required for successful transition to employment and academia. Note the decrease (16.5%) in the number of schools that have not recorded any results gaining credits for AS 90190 in 2006, and an increase in all other standards except unit standards at level 3. The increase in the number of schools recording credits for NZASE certificate credits (at lower curriculum level expectations) is a concern for future viability of the subject. This may reflect competition by schools to provide evidence that they are 'adding value' by showing that more students are gaining credits. It may also reflect that schools may perceive that in this subject area, there is a greater chance of gaining credits for NCEA level one by doing NZASE certificate standards at the expense of higher curriculum levels. This would enable schools to honour the idea of Geoscience being an essential part of the curriculum but would also allow students to gain credits in a subject area where there is less teacher competence, confidence, and resourcing. This may suit perceived school and teacher needs but not necessarily student needs. Students do not choose what courses of study are offered: school Science departments do. Hypothetically, and supported by the increase of NZASE and US credits, the gaining of credits in geoscience appears to be a more important goal for schools than developing higher levels of student understanding about planet Earth.

3. For students to advance their studies in geology beyond the compulsory curriculum years of up to Year 10, the only way currently is for schools to offer the subject of Science at Years 12 and 13 (i.e. NCEA Levels 2 and 3 or age 16/17/18) **or** offer unit standards. Geology is not a stand alone subject and ideally makes up 25% of a year's course in Science. However, only 8% of 434 schools actually offered Level 3 Science and 11% offered Level two Science, so studying Geology effectively dies at age 16 (end of Year 11) and of those students who gained credits in Geology at Level 1, 46% were at curriculum Level 4/5 and 45% at curriculum level 6. The level of conceptual knowledge of geological processes across the whole population is therefore likely to be very low.

The distributions of results gaining credit across all standards that contribute to learning and assessment in the geological sciences for 2005 to 2007 (Figure 9.16) Results are published in April of the following year on www. nzqa.

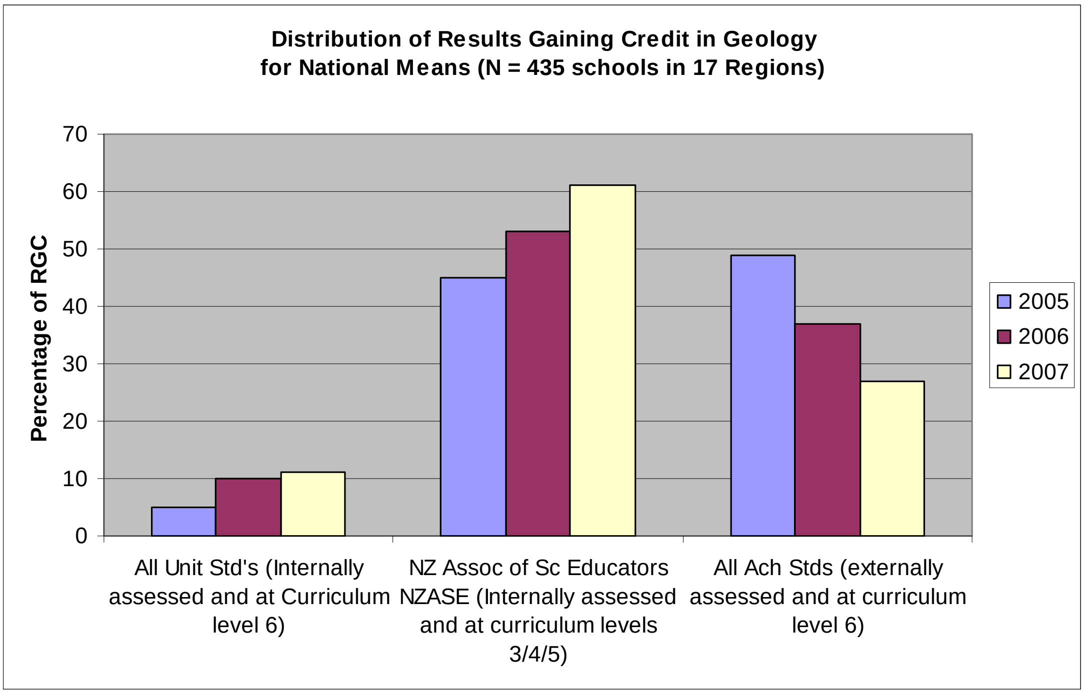
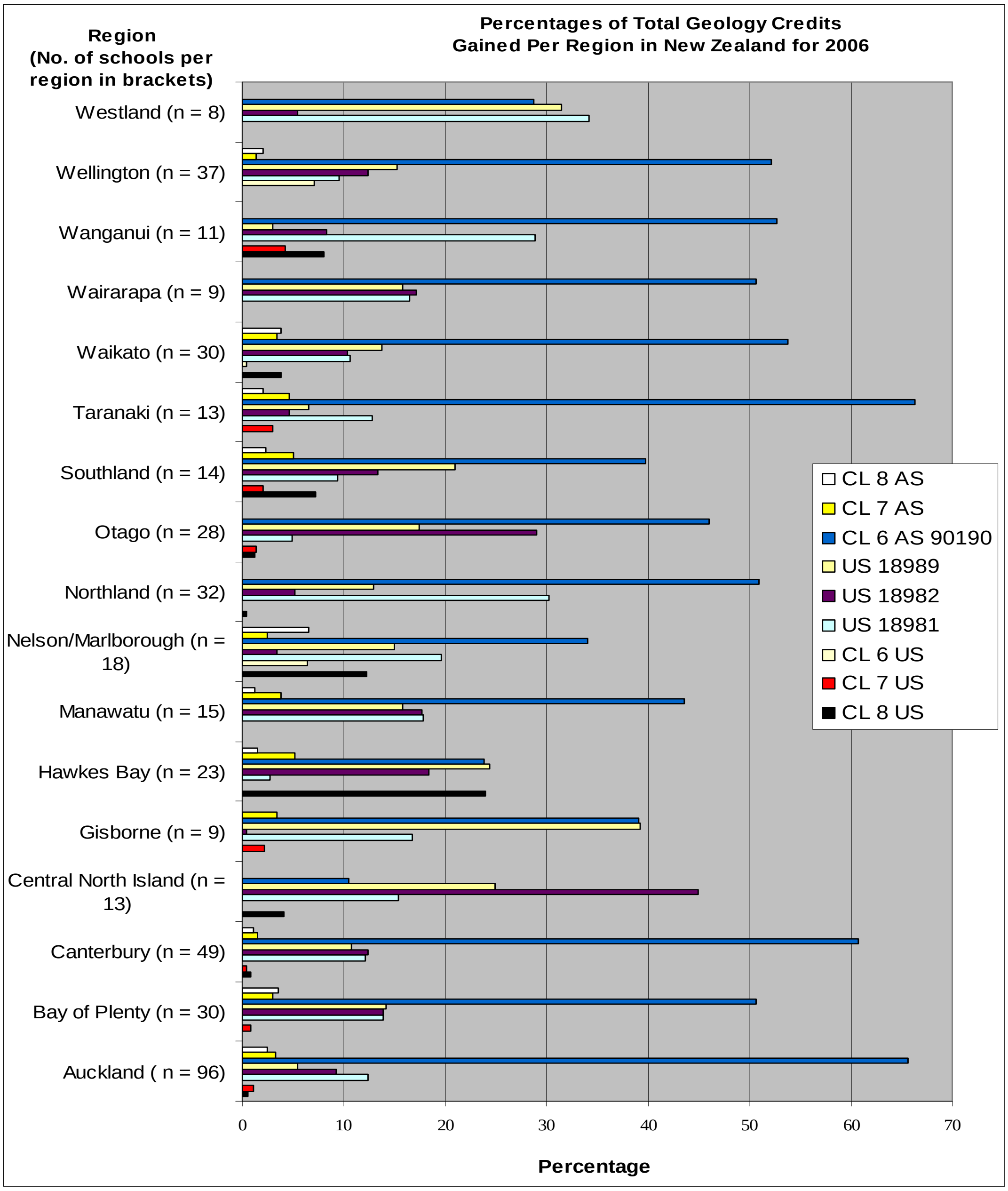


Figure 9.16. Standards contributing to results gaining credit in geological science.

These results indicate that the numbers of schools (Figure 9.16) and therefore candidate numbers learning and being assessed in the geological sciences, continues to decline (note that Astronomy is not considered here as a geological science, but is part of the Planet Earth and Beyond strand of the national curriculum). The key aspect of these changes is that the growth of NZASE credits for NCEA level 1 (and at the lower curriculum levels of 3, 4 and 5) is at the expense of the achievement standards.

The achievement standard AS 90190 (Aspects of Geology) at Year 11 dominates these credits with around only 40 to 50 schools gaining student credits in geology at Years 12 and 13. Students gain their credits for level 1 NCEA in geological science dominantly through internally assessed low curriculum level NZASE standards rather than from higher level externally assessed examinations in achievement standards. Only around 10% of credits gained come from unit standards which are also internally assessed and do not cover the same concepts as achievement standard AS 90190 “Aspects of Geology”.



Key:
CL = National Science curriculum level. 189xx = NZASE standards
US = Unit Standards. AS =Achievement Standards

Figure 9.17 Regional results that gain credits in Geology.
N = 434 Secondary Schools.

The new 2010 Science curriculum will change all this again with emphasis on Earth Systems and Earth's surface features rather than geological aspects of history, fossils and time. A new curriculum implies different conceptual assessment and comparative data will be not possible after 2011. It is likely that the current trends in credit distributions will continue with the extinction of Year 11 geology imminent.

3. Figures 9.17 and 9.18 provide a breakdown of internal and external student examination results that gain them credit in Geology assessment standards by geographic region. Unit standards are internally assessed or in the case of NZASE standards, ‘commercially’ available with essentially all students sitting a pre-existing task.

Most unit standard assessment tasks are derived from materials developed by the National Qualifications Authority in June 1998 (NZQA Assessment Guide). The authenticity, validity and reliability issues involved (and associated NZQA moderations) in the continued unmodified use of these materials for students in gaining credit by unit standards in 2008 are obvious. Although NZASE unit standards have undergone some ‘cosmetic’ revision in 2006, assessment tasks have remained essentially the same.

Achievement standard 90190 *“Aspects of Geology”* (blue bars in Figure 9.17), is a key geology assessment standard because the majority of schools and the maximum number of students are involved and with the teaching and learning of geological science at secondary school barely existing beyond this level. Hawkes Bay region is notable for the large percentage of results (24%) generated from curriculum level eight standards and the relatively low percentage (23%) generated from AS 90190. It is even more notable that in this region there are no credits generated from curriculum level 7 or Year 12. In fact, only 41% of all regions recorded any results derived from Level 7 assessments and with large regions such as Canterbury and Auckland having less than 3% of their results generated from this level. The percent change in results gaining credits (Figure 9.20) from 2005 to 2006 also reveals regional differences in choices that schools are making for the teaching of Geology at national qualifications levels.

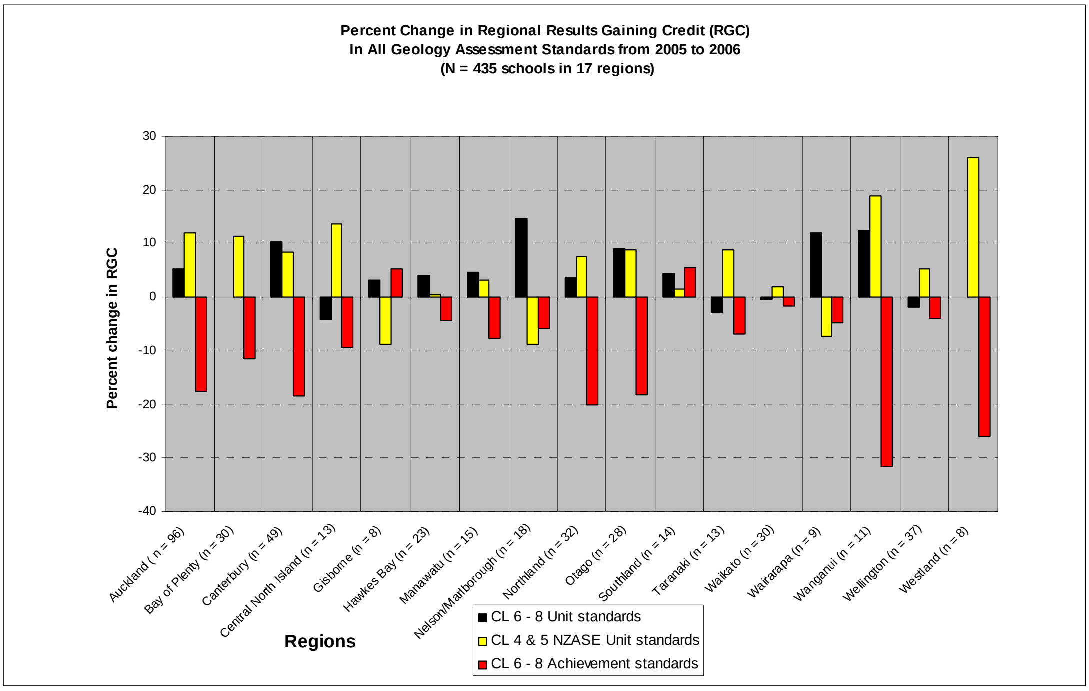


Figure 9.18. Percent change in results gaining credit for Geology 2005 – 2006.

Other than very small increases in Southland and Gisborne regions, there is a clear overall decrease in the percentage of students gaining credits from achievement standards suggesting that these standards are perceived as not meeting the needs of teachers and students and therefore not taught. These two regions which show increases in results derived from achievement standards may represent traditionally enthusiastic teachers and Science departments with large investments in resources. Waikato region has a traditionally strong university Department of Earth Sciences and a teachers' training college of education; this may account for the relatively small decrease in credits gained from achievement standards. The region has been consistently strong in teaching the Earth Science and this tradition seems to have been maintained indicated by small changes in results gaining credits from all sources. Because so few schools offer curriculum levels 7 and 8 achievement standards, level 6 (AS 90190) accounts for most of the decrease. In summary, the average decrease in results derived from achievement standards is 10%, with an average increase of 6% in curriculum level 4/5 NZASE standards and an average increase of 4.5% in all other unit standards.

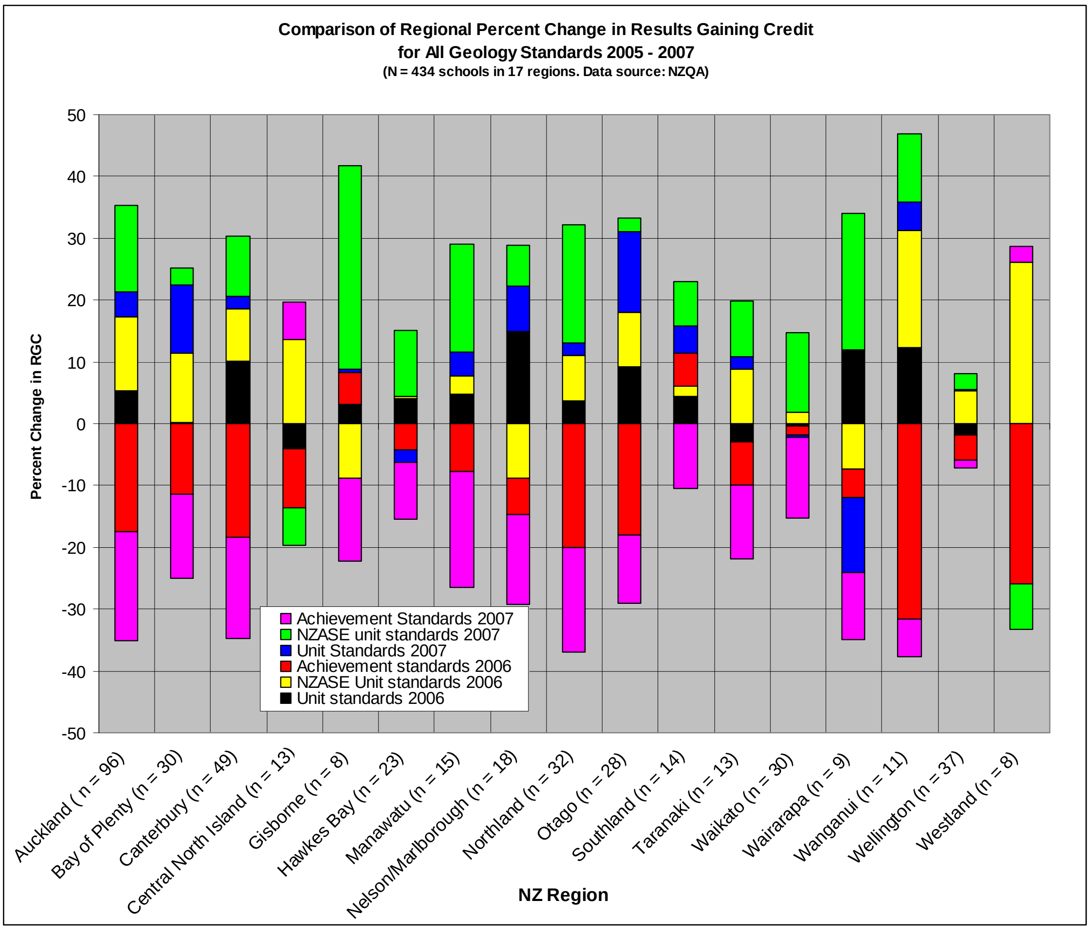


Figure 9.19. Comparison of regional changes in results gaining credit for Geology 2005 – 2007.

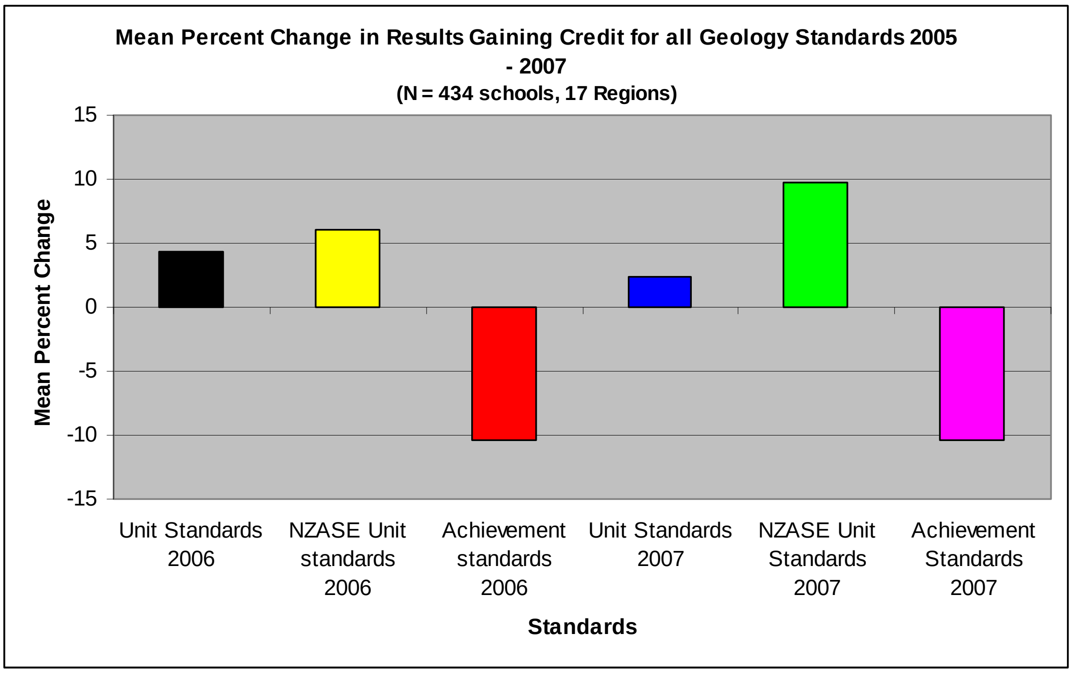


Figure 9.20. Mean percentage change in Geology standard credits.

Figure 9.19 shows the actual percent regional change and Figure 9.20 shows the **mean** change for all geology standards that contributed to candidate results gaining credit from 2005 to 2007. Importantly, the New Zealand Association of Science Education (NZASE) standards continue to grow at the expense of all other geology standards. Why? But note future changes discussed in the postscript.

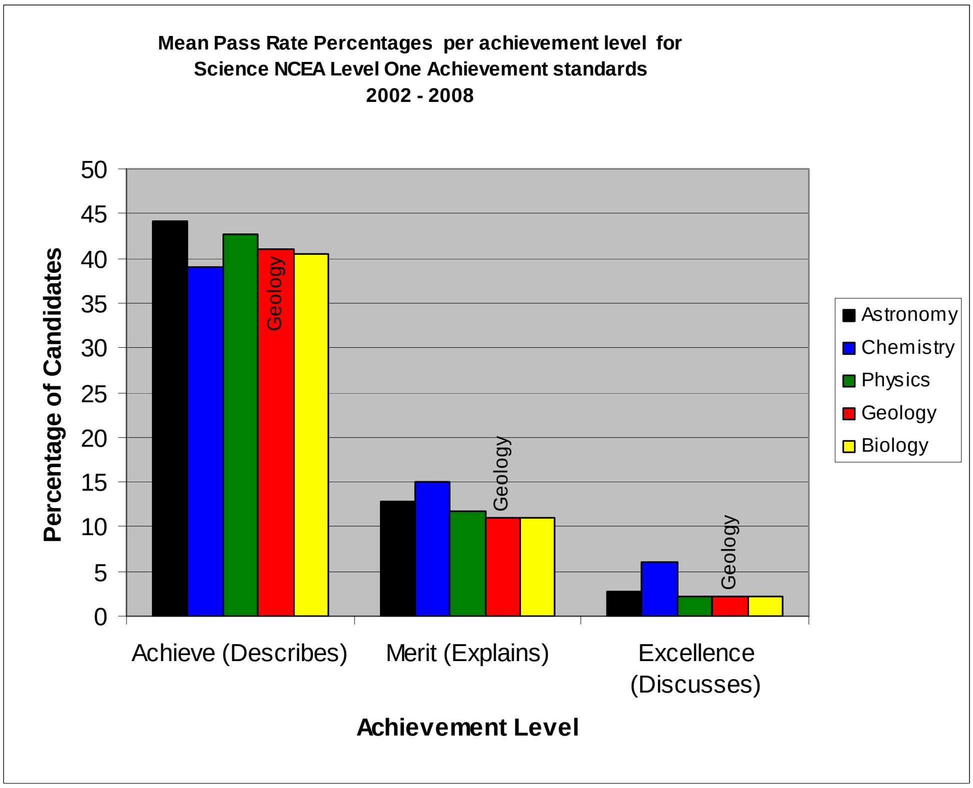


Figure 9.21. Comparison of mean achievement results for NCEA Level 1 Science.

Figure 9.21 compares the percentage of achievement levels between externally examined standards that contribute to the national Science curriculum at level 1 (15/16 year olds). Results are for external examinations and show the percentage of students gaining descriptive achievement, explanatory merit and discursive excellence from the introduction of NCEA Level 1 in 2002 to 2007. Physics, chemistry and biology contribute five credits each whereas Geology contributes three credits and Astronomy two credits (making up *Planet Earth and Beyond*). Geology achievement performances are not significantly different to the national means of 43% (43.1%) gaining achieve, 12% (10.3%) gaining merit and 2.9% (2.2%) gaining excellence (Geology in brackets). It is important that achievement levels of attainment are not construed as equating to broad percentage mark bands. Excellence does not equate to students achieving 80% or more in any one examination as in norm referencing. It equates to students who (a) demonstrate a criteria referenced knowledge base via rigorously moderated questions and assessment schedules, (b) are able to explain conceptually and (c) are able to link ideas and concepts in explanation of geological principles as set out in the achievement standard criteria.

Despite seriously declining candidate numbers in both Geology and Astronomy (Figure 9.1 in text and 9.21 in this Appendix), arguments suggesting that students who do not study Geology are disadvantaged on the grounds that it is more difficult than the other sciences, is not supported by the evidence. Figure 9.21 indicates that there is very little difference in achievement levels for each of the sciences offered at level 1. Although Astronomy (like Geology) attracts fewer numbers of candidates (Figure 9.1 in Chapter 9) it produces a higher number of students who achieve at each level except for chemistry at merit and excellence levels.

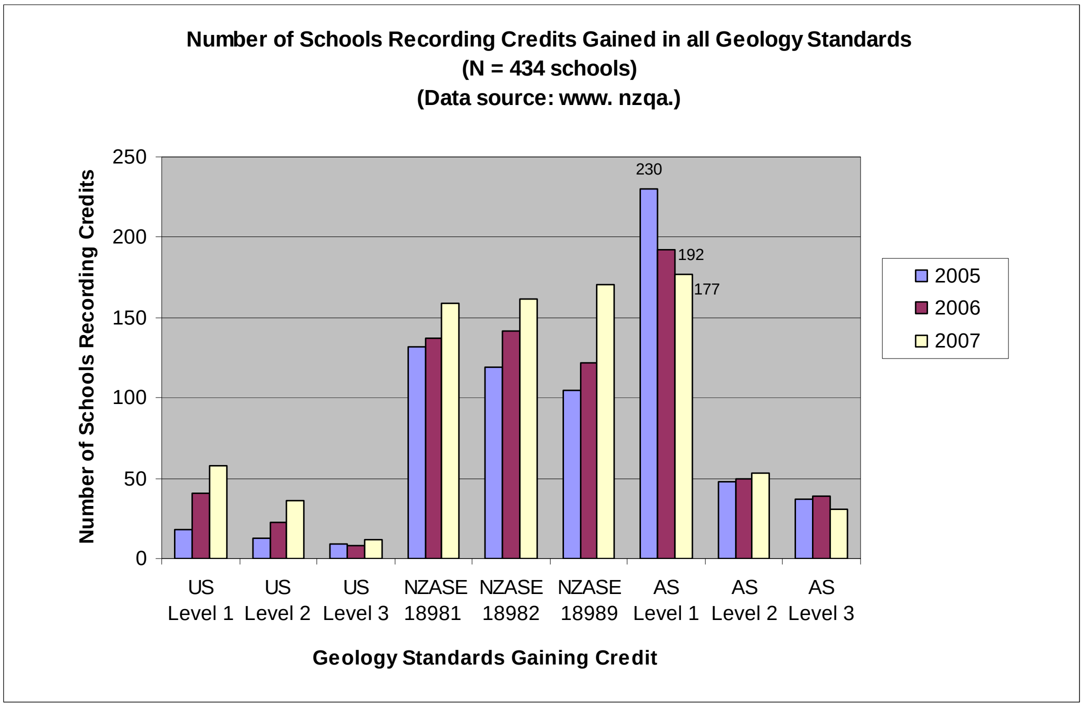


Figure 9.28. Total number of New Zealand secondary schools offering Geology assessment standards.

APPENDIX 4

Scale of Objects Questionnaire (SOQ) Assessment

This sheet asks about your perceptions of objects of different sizes. Please consider each of the following objects and indicate the size of each one. **Please ''X'' OR TICK the box that is closest to your own opinion. Please try to respond honestly to each item.**

	A	B	C	D	E	F	G	H	I	J	K	L
	<0.0000001mm	<0.001mm	.01mm to 1mm	1mm to 1cm	1cm to 1 dm	1dm to 1m	1m to 10 m	10m to 100m	100m to 1000m	1000m to 1million m	I million m to 1 billion m	>1billion m
1.Width of a human hair												
2.Length of a football field												
3.Distance from Earth to Moon												
4.Diameter of a virus												
5.Diameter of the Earth												
6.Height of the world's tallest Building												
7.Diameter of a hydrogen atom												

	A	B	C	D	E	F	G	H	I	J	K	L
8.Distance from Auckland to Invercargill												
9.Diameter of a human cell												
10.Diameter of the nucleus of a carbon atom												
11.Length of an ant												
Height of an elephant												
12.Altitude of an artificial satellite above Earth												
13.Diameter of a Bacterium												
Height of a typical adult person												
14.Length of a new Pencil												
15 Length of a school Bus												

	A	B	C	D	E	F	G	H	I	J	K	L
16.Distance from theEarth to the Sun												
17.Length of a grain of white rice												
18.Length of a postage stamp												
19.Height of a mature pine tree												

A B C D E F G H I J K L (Key was provided on a separate piece of paper)

Key for tick-boxes: **A**: less than 1 billionth of a meter [less than 1 nanometer (1 nm)]; **B**: between 1 billionth and 1 millionth of a meter [between 1 nanometer (nm) and 1 micrometer (1 mm)]; **C**: between 1 millionth and 1 thousandth of a meter [between 1 micrometer (1 mm) and 1 millimeter (1 mm)]; **D**: between 1 thousandth and 1 hundredth of a meter [between 1millimeter (1 mm) and 1 centimeter (1 cm)]; **E**: between 1 hundredth and 1 tenth of a meter [between 1 centimeter (1 cm) and 1 decimeter (1 dm)]; **F**: between 1 tenth of a meter and 1 meter [between 1 decimeter (1 dm) and 1 meter (m)]; **G**:between 1 meter and 10 meters; **H**: between 10 meters and 100 meters; **I**: between 100 meters and 1000 meters; **J**: between 1000 meters and 1 million meters; **K**: between 1 million meters and 1 billion meters; **L**: over 1 billion meters

.Table 6.7. Year 12 Ashburton College: Individual response distribution of rankings of Size boundaries (after Tretter et al. 2006) n = 21

Object	Q' No.	Actual Size rank	Actual rank by categor y A-L	Student mode score A -L	A <0.0000001 mm	B <0.01mm to 1mm	C 0.01mm to 1cm	D 1mm to 1cm	E cm to 1dm	F 1dm to 1m	G 1m to 10m	H 10m to 100m	I 100m to 1000m	J 1000m to 1 million m	K 1 million m to 1 billion m	L >1 billion m	Agreement (00 =agree)
Earth to Sun	18	21	L	L	0	0	0	0	0	0	0	0	0	0	2	19	OO
Earth to Moon	3	20	K	L	0	0	0	0	0	0	0	0	0	0	8	13	I
Earth diameter	5	19	K	K	0	0	0	0	0	0	0	0	0	4	9	6	OO
Satellite altitude	13	17	J	J	0	0	0	0	0	0	0	0	0	9	6	5	OO
Auckland to Invercargill	8	18	J	J	0	0	0	0	0	0	0	0	0	14	6	0	OO
Tallest building	6	16	I	I	0	0	0	0	0	0	0	0	16	7	0	0	OO
Football field	2	15	H	H	0	0	0	0	0	0	0	11	10	0	0	0	OO
Pine tree	21	14	H	H	0	0	0	0	0	0	0	19	1	0	0	0	OO
School bus	17	13	G	G	0	0	0	0	0	0	15	3	3	0	0	0	OO
Elephant height	12	12	G	G	0	0	0	0	0	0	20	1	0	0	0	0	OO
Human adult height	15	11	G	G	0	0	0	0	0	1	19	0	0	0	0	0	OO
New pencil length	16	10	E	E	0	0	0	0	14	5	1	0	0	0	0	0	OO
Postage stamp	20	9	E	E	0	0	0	0	19	1	0	0	0	0	0	0	OO
Rice grain	19	8	D	D	0	1	2	18	0	0	0	0	0	0	0	0	OO
Length of an ant	11	7	D	D	1	2	3	14	1	0	0	0	0	0	0	0	OO
Width of human hair	1	6	C	B	8	10	3	0	0	0	0	0	0	0	0	0	I
Human cell diameter	9	5	B	A	14	5	2	0	0	0	0	0	0	0	0	0	I
Bacteria diameter	14	4	B	A	13	6	1	0	0	0	0	0	0	0	0	0	I
Virus diameter	4	3	B	A	17	3	0	1	0	0	0	0	0	0	0	0	I
H atom diameter	7	2	A	A	20	1	0	0	0	0	0	0	0	0	0	0	OO
C nucleus diameter	10	1	A	A	17	4	0	0	0	0	0	0	0	0	0	0	OO

Table 6.8. Year 9 Ashburton College: Individual response distribution of rankings of Size boundaries (after Tretter et al. 2006) n =19

Object	**Q'n No.**	**Actual size rank**	**Actual by category A-L**	**Student mode score category A-L**	**A <0.0000001m m**	**B <0.01mm to 1mm**	**C 0.01mm to 1cm**	**D 1mm to 1cm**	**E cm to 1dm**	**F 1dm to 1m**	**G 1m to 10m**	**H 10m to 100m**	**I 100m to 1000m**	**J 1000m to 1 million m**	**K 1 million m to 1 billion m**	**L >1 billion m**	**Agreement (00 =agree)**
Earth to Sun	18	21	L	L	0	0	0	0	0	0	0	0	0	1	2	13	OO
Earth to Moon	3	20	K	L	0	0	0	0	0	0	0	2	0	2	3	12	I
Earth diameter	5	19	K	L	0	0	0	0	0	0	0	0	1	2	4	8	I
Satellite altitude	13	17	J	K	0	0	0	0	0	0	0	2	2	2	7	2	I
Auckland to Invercargill	8	18	J	J	0	0	0	0	0	0	0	0	1	9	5	2	OO
Worlds tallest building	6	16	I	J	0	0	0	0	0	0	0	0	7	9	2	0	I
Football field	2	15	H	H	0	0	0	0	0	0	0	9	7	0	0	0	OO
Pine tree	21	14	H	G	0	0	0	0	0	0	9	6	0	0	1	0	I
School bus	17	13	G	G	0	0	0	0	0	0	13	2	2	0	0	0	OO
Elephant height	12	12	G	G	0	0	0	0	0	1	14	2	0	0	0	0	OO
Human adult height	15	11	G	G	0	0	1	1	0	1	13	0	0	0	0	0	OO
New pencil length	16	10	E	E	0	0	0	2	10	3	0	0	0	0	0	0	OO
Postage stamp	20	9	D	D	0	1	6	1	6	1	1	0	0	0	0	0	OO
Rice grain	19	8	D	C	1	5	4	3	2	0	0	0	0	0	0	0	I
Length of an ant	11	7	D	B	2	9	3	3	0	0	0	0	0	0	0	0	I
Width of human hair	1	6	C	A	11	1	2	2	2	0	0	0	0	0	0	0	I
Human cell diameter	9	5	B	?	5	2	4	2	2	0	1	0	0	0	0	0	I
Bacteria diameter	14	4	B	A	6	2	4	0	0	1	0	0	0	0	0	0	I
Virus diameter	4	3	B	A	7	0	3	0	1	2	0	0	0	1	0	0	I
H atom diameter	7	2	A	?	3	4	2	0	0	4	0	1	1	1	1	0	I
C nucleus diameter	10	1	A	?	6	1	1	1	1	2	2	0	1	0	0	0	I

Red means significant indecision

Yellow means disagreement with actual (48-62%)

Blue means agreement with actual

APPENDIX 5

Earth Science and Evolution Questionnaire

Instructions:
These questions are designed to gather information about how students of different ages and from different countries understand aspects of fossils and evolution so that teachers can improve the way topics can be taught. **Your name is not required and this is not a test which counts towards any certificates or awards.** Your answers to 'about yourself' will help make sense of some of the responses that you make and any codes on these sheets are for administrative reasons only. The questions are for all age groups to respond to. Your answers are totally confidential and no individual will be identifiable in any future publication.

Please write your answers in the spaces provided where appropriate

About Yourself (fill in only if you have not already done so or go to Section A)

1. How old are you? Years ……………. months ………………..

2. Are you male or female? ……………………………….

3. What country were you born in? ……………………………….…..…

4. What religious affiliation do you identify with? ……………………

5. What is or was your favourite school subject? ………………………

6. When did you last study any geology (Earth Science)? ………………

Section A Ideas about fossils

1. Do you think the following ideas about fossils are true or false (tick in the true or false column).

	Your Ideas About Fossils	True	False
1	Fossils grow from seeds inside rocks		
2	Fossils are the failed creations of God		
3	Fossils are tricks of the devil		
4	Fossils are just accidents of nature		
5	Fossils are the preserved parts of once living organisms		
6	Fossils are the preserved parts of extinct organisms only		
7	Fossils are important and interesting		
8	Fossils support the theory and fact of evolution		
9	Charles Darwin was the first person to think of evolution		
10	Human beings have evolved from apes		
11	The oldest known fossils are about 3.4 billion years old		
12	A scientific theory is just a guess		

13	Birds are the living descendants of the dinosaurs		
14	The Earth was made in six days		
15	All living things share the same basic DNA coding system		
16	New species appear suddenly in the fossil record after a long period of stability		
17	The fossil record suggests that evolution occurs by slow and gradual change from one species into another		
18	The scientific method only involves the controlled testing of hypotheses		

2. Write an explanation for **any two** statements you thought were **true**

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

3. Some people think that the draining away of a great flood of water explains how fossils can be found near the tops of high mountains. How do you think they got there?

……………………………………………………………………………………

……………………………………………………………………………………

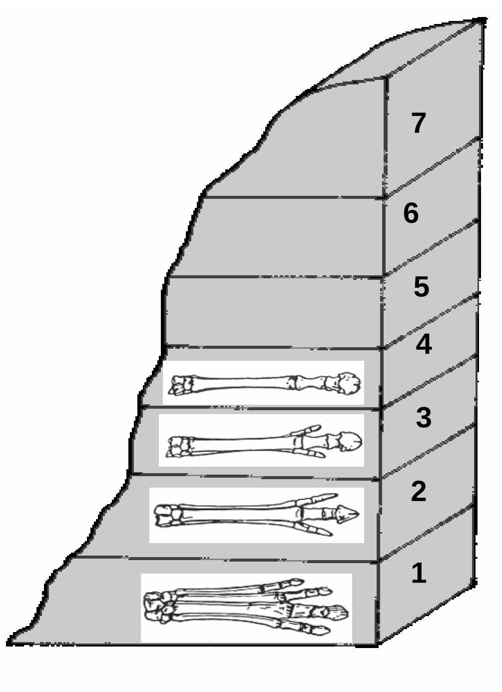
……………………………………………………………………………………

……………………………………………………………………………………

Section B Using Fossils

1. **(a)** The illustration below represents rock layers containing fossils. The fossils are the remains of bones from the feet of an unidentified land living animal.

Describe in words the changes that took place in the **fossil feet** between rock layer 1 and rock layer 4.



Description of changes in foot bones
………………………………………
………………………………………
………………………………………
………………………………………
………………………………………
………………………………………
………………………………………
………………………………………

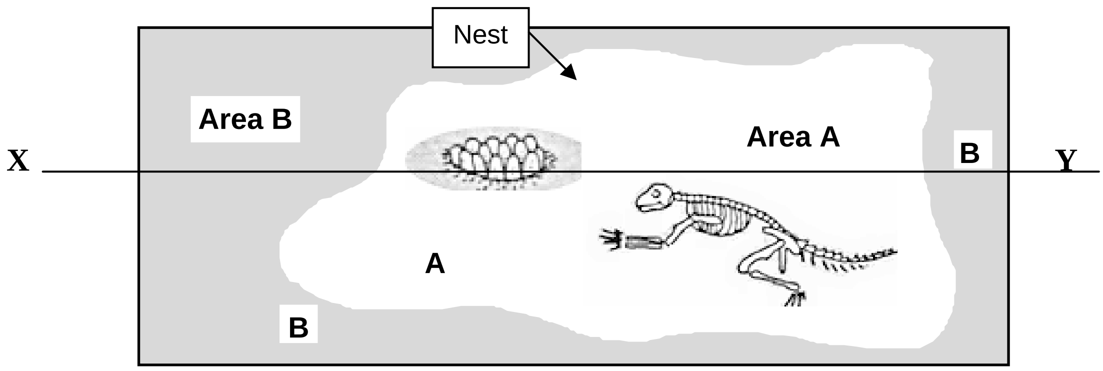
1. (b) Suggest 2 possible reasons for the absence of fossils after rock layer 4.

…………………………………………………………………………………….

…………………………………………………………………………………….

…………………………………………………………………………………….

2. The illustration below represents a dinosaur excavation site. This excavation can be broken down into two areas A and B.



Area A:

This is built of sedimentary rock of land origin and contains the skeletons of dinosaurs. Two important points can be noted about this area:

1. *The dinosaur skeletons range in size from very tiny to very large. This suggests that in this area, the age range of the dinosaurs was broad, ranging from newly hatched babies to fully-grown adults.*
2. *A large number of nests containing fossilised eggs were discovered.*

Area B:

This area surrounds area A and is made of marine (ocean or seafloor) sedimentary rock containing fish.

(a) Draw in the box a cross section from X to Y (see diagram above) of how this excavation site might have looked when the dinosaurs were alive.

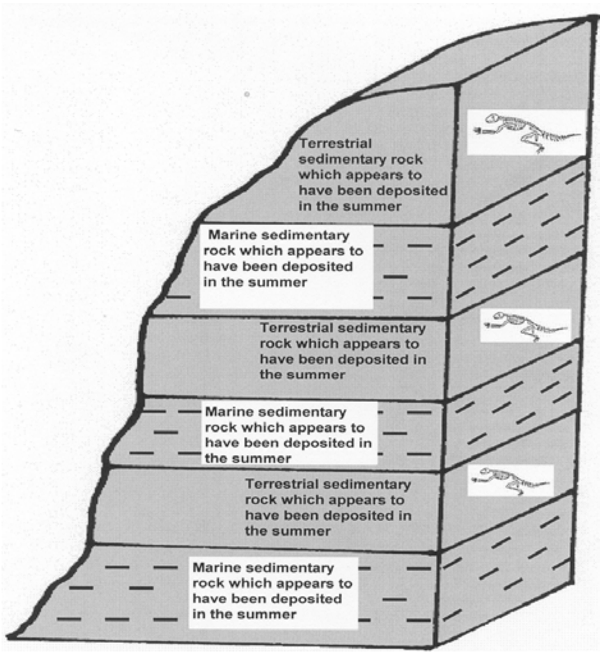
***2 (*b)** What could you say about the fact that in one single area scientists have found a species of dinosaur ranging in size and age from egg to adult?

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

(c) When scientists dug down into this area they found an alternating arrangement of layers consisting of marine (sea floor) sedimentary rock containing no fossils and land sedimentary rock containing dinosaur fossils (see illustration below).



In a geological sense what do you think this alternating arrangement of layers might mean?

…………………………………………………………………………………………….

…………………………………………………………………………………………….

…………………………………………………………………………………………….

…………………………………………………………………………………………….

…………………………………………………………………………………………….

…………………………………………………………………………………………….

(d) What do you imagine the Earth would **look like, and sound like** when it was first formed compared with today? Eg hot, cold, loud, quiet, green, brown, white, bigger, smaller etc.

First Formed		**Today**	
Look like	Sound like	Look like	Sound like

3. Fossils and Time

This question is about your perception of some major geological events. Put the following individual geological events into what you think is their correct time of occurrence using the letters A to J below. Event 25 is done for you as an example.

Age range to choose from:

- **A** Less than 100 years ago
- **B** 100 to1000 years ago
- **C** 1000 to100,000 years ago
- **D** 100,000 to1 million years ago
- **E** 1 million to10 million years ago
- **F** 10 million to100 million years ago
- **G** 100 million to1 billion years ago (1 billion = 1000million)
- **H** 1 billion to5 billion years ago
- **I** 5 billion to one million million years ago
- **J** More than a million million years ago

Please write an answer for each event. Write the letter beside the event in the column marked age range.

	Geological Event	**Age range I think it is (choose from A-J)**	**Actual age in years (If known)**
1	The first fish appear on Earth		
2	The Earth's crust is formed		
3	Formation of the Earth		
4	Theory of plate tectonics is developed		
5	Large dinosaurs became extinct		
6	The Ice Age		
7	First appearance of land animals		
8	Trilobites became extinct		
9	Formation of the Sun		
10	Formation of the first rocks on Earth		
11	Woolly Mammoths become extinct		
12	Formation of the Moon		
13	Appearance of the first life forms on Earth		
14	Big Bang formation of the Universe		
15	Appearance of the first birds		
16	Appearance of the first dinosaurs		
17	First life forms with shells or bones		
18	Appearance of first humans		
19	Eruption of the first volcanoes on Earth		
20	The beginning and opening of the Atlantic Ocean		
21	Appearance of the first trees		
22	Formation of the oldest rocks in your country		
23	The beginning of time		
24	Formation of the Milky Way galaxy		
25	**Galileo was put under house arrest**	**B**	**AD 1616**

THANK YOU FOR PARTICIPATING

APPENDIX 6

The association/concept maps in Figures 10.1 and 10.2 show elements of learnt conceptual development about biological evolution but little indication of developed linkages. That is, these maps illustrate a collective conceptual knowledge but with no feedback linkages.

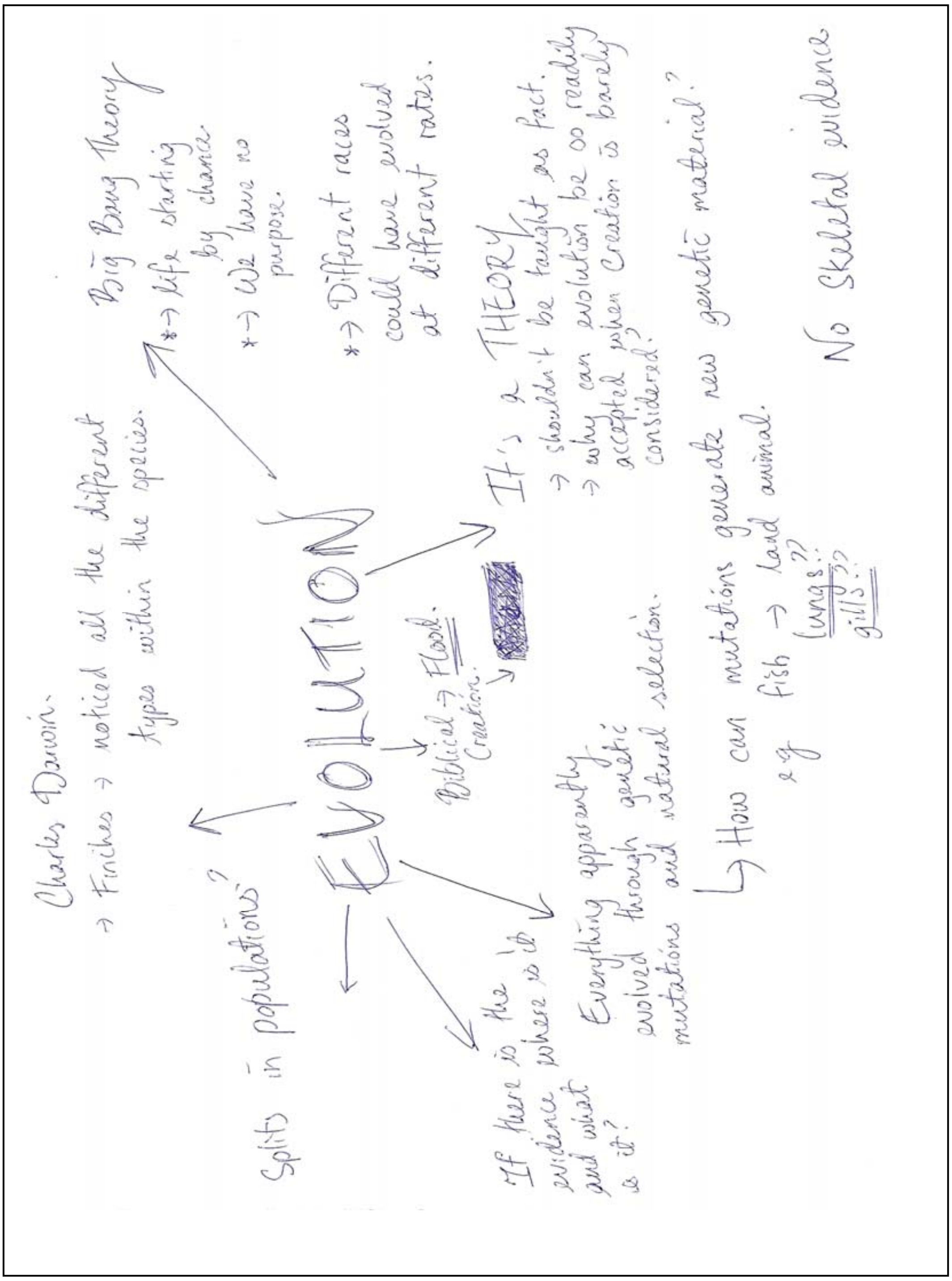


Figure 10.1. A New Zealand Year 12 ‘evolution’ concept map.

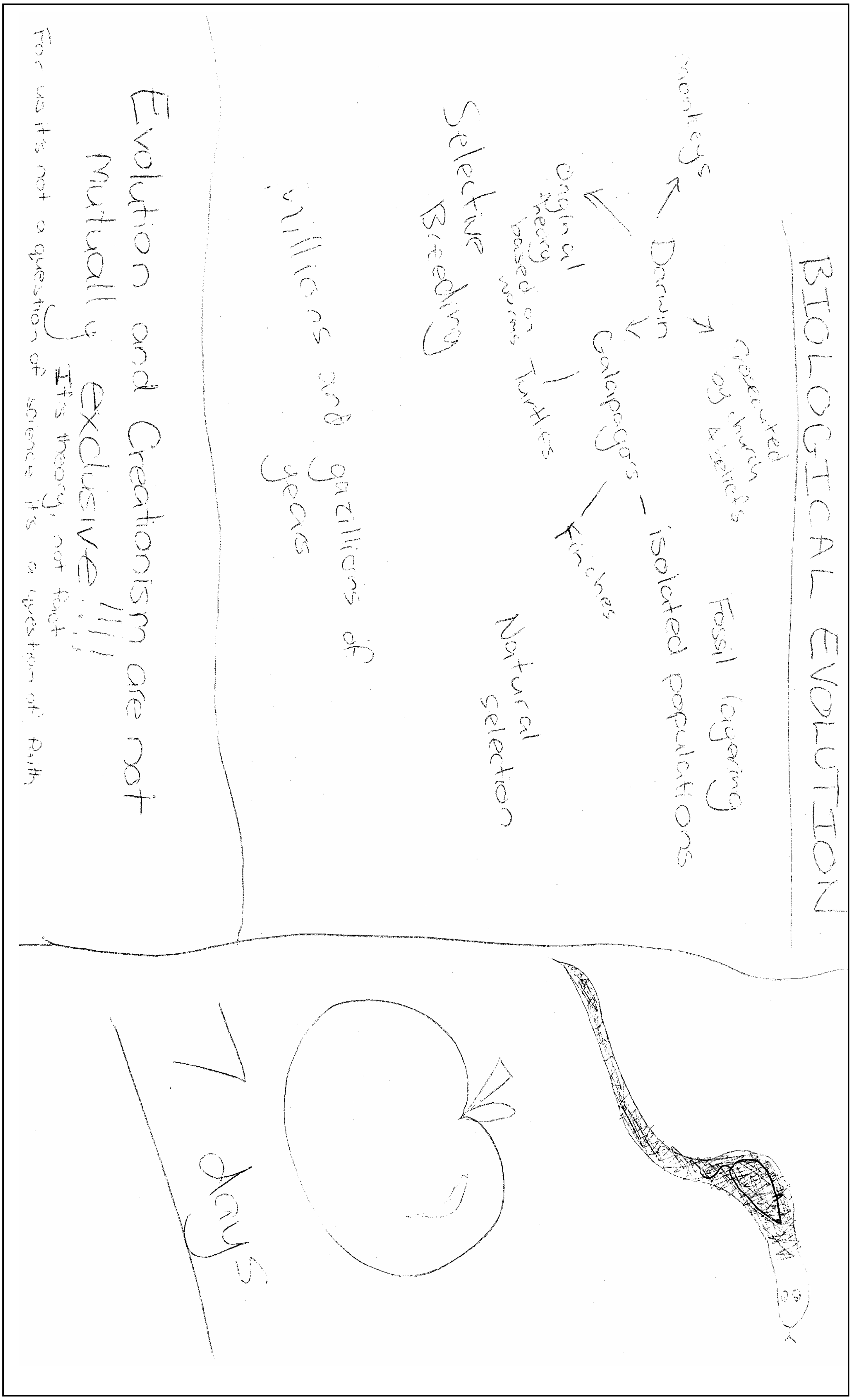


Figure 10.2. A contrasting New Zealand Year 12 ‘evolution; concept map.

New Zealand Case Study of Evolution in a National Curriculum

Background

Biology as a separate subject of learning in the New Zealand curriculum begins at age 15 (NZ Year 11) and ends at age 17/18 at Year 13, the final year of secondary schooling before entry to university. The majority of secondary schools begin teaching Biology at Year 12 with an average age of 16 years of age. Current contextual curriculum achievement aims (Ministry of Education, 1994) indicate strong connections between genetics and evolution. Achievement objectives are derived from the achievement aims. As mentioned in Chapter 8, the NZ curriculum was revised in November 2007 (Ministry of Education, 2007) with full implementation in 2011. This revision formally recognises evolution as a vital part of biological science within the "Living World" strand of the science curriculum. show The achievement objectives specifically for evolution content are shown in Tables 10.1 (the 2007 revised NZ curriculum) and 10.2 (the 1994 curriculum) in Chapter 10, but these broad statements for the 2007 curriculum reform are yet to be unpacked into specific learning objectives. In tandem with those objectives are the national assessment qualification standard statements which are derived from curriculum objectives. Some qualification standards may change in focus as a result of the 2007 curriculum revisions in biology but in effect 'standards' become the content that teachers teach and what students learn.

Although the school leaving age is 16 years, curriculum Levels 1 to 6 are the years in which 'compulsory' evolutionary concepts to which all students will be exposed. The degree of exposure is determined by individual teacher expertise and school department policies. After Level 5 (but mostly from Level 6), sciences in NZ split into the traditional physics, chemistry and biology and as a consequence around 25-30% of a Year 9 intake (first year high school students) will study biology at Year 12 (curriculum Level 7), and around 10-15% of that same Year 9 intake will study biology in their final year at high school. As described in Chapter 8 very few schools offer Levels 7 and 8 Science and as a consequence few students learn any detail of biological evolution through this route. The only external examination for evolution related aspects at Year 12, is part of an achievement standard on genetic variation and change the same as currently. There are two external achievement standards at

Year 13 dealing with evolution: *1. Describe evolutionary processes leading to speciation and 2. Describe trends in human evolution.* It remains an issue that so few students will ever study processes of biological evolution.

Table 10.9. Evolution Achievement Objectives in the 2007 revised curriculum (For implementation in 2010).

Curriculum Level (CL)	**Achievement Objectives (2007 revised NZ curriculum)**
Levels 1and 2 (Age 5/10 years)	Recognise that there are lots of different living things in the world and that they can be grouped in different ways. Explain how we know that some living things from the past are now extinct.
Levels 3 and 4 (Age 11/14 years)	Begin to group plants, animals and other living things into science-based classifications. Explore how the groups of living things we have in the world have change over long periods of time and appreciate that some living things in NZ are quite different from living things in other areas of the world.
Level 5 (Age 14/15 years)	Describe the basic processes by which genetic information is passed from one generation to the next.
Level 6 (Age 15/16 years)	Explore patterns in the inheritance of genetically controlled characteristics. Explain the importance of variation within a changing environment.
Level 7 (Age 16/17 years)	Explain how the interaction between ecological factors and natural selection leads to genetic changes within populations.
Level 8 (Age 17/18 years)	Explore the evolutionary processes that have resulted in the diversity of life on Earth and appreciate the place and impact of humans within these processes.

Curriculum Level 2 is the dominant entry point into biological studies at school and beyond. Unit standards, which are competency based, is completed by significantly fewer schools and students and are not discussed in detail here. Currently, Level 1 has no evolution content. As explained in chapter 9, national qualifications are derived from achievement and/or unit standards and for evolution studies at curriculum Level 2, the vast majority of students gain credits from the externally set and managed examination AS 90459, “Describe genetic variation and change”. Evolution makes up around 35% of this standard and involves the following topics: allele and gene frequency changes, mutation as a source of variation, natural selection, migration, genetic drift, founder effect and gene pool bottleneck. The links between the genetic basis of evolutionary micro and macro evolution (and at the molecular level) are clear, but the pedagogical and content links with the morphological and deep time scale of the fossil record is not. It is also clear that after 36 years of classroom observation that students of biology (age 16 to 18 years) have great difficulty conceptualising populations and populational genetic turnover. It is precisely this link between populational genetic turnover, natural selection and chance that is diminished (3 to 5 hours of tuition time at Year 12) from curricula on evolution and also often fails to take into account the explanatory power of the fossil record.

Table 10.10. Typical content for the teaching of evolution in Biology.
(Based on pre-revised 1994 Biology curriculum).

Year 12 (CL2) (8 to 12 hours tuition time)	**Year 13 (CL3)** (20 to 25 hours tuition time)
Evidence for evolution: Comparative anatomy The fossil record Genetic code Protein analysis	**Understanding the scientific theory and fact of evolution:** Historical perspectives Review of evidence Neo-Darwinism Agents of gene pool change Types of natural selection Punctuationism and gradualism
Evolution in populations: Gene pools and gene flow Sources of variation Natural selection	**Speciation:** Types Isolating mechanisms
Speciation: Isolating mechanisms Rate of change Selection pressure Adaptive radiation	**Modes of evolution:** Extinction Patterns of evolution Analogous and homologous structures
	Comparison of living hominoids
	Comparison of hominid species: Main lineages Fossil locations
	Trends in cultural evolution

Although many studies have been conducted on students' conceptual frameworks and ecologies on evolution, (Bishop, 1990; Brumby, 1984; Demastes, 1995; Dodick, 2007; Hallden, 1988), exploring specifically why students do not appear to translate evolution as occurring at the population level rather than at the individual level is worthy of further research. Perhaps this is related to notions of genes and genetics being perceived as being only related to individuals rather than populations in a similar way to time scales (and other scalar dimensions) being consistently related to the individual as the primary reference point. Mayr (2001) succinctly pointed out the connection between micro and macro evolutionary scales: a source of persistent difficulty, misconception and perception about the evolution of new species, orders and genera.

> *" ..all macro evolutionary processes take place in* ***populations*** *and in the genotypes of individuals, and are thus simultaneously micro evolutionary processes"*(Mayr, 2001, p.190).

For NZ curriculum Level 3, topics in AS 90719: Describe trends in human evolution" include: trends and patterns in human biological (especially skeletal and dextral) and cultural evolution. Explanatory notes for this standard indicate that evidence relating to human evolution must be scientific evidence which is widely accepted and presented in peer-reviewed scientific journals. This prevents the inclusion of non scientific material. For AS 90717 "Describe processes and patterns of evolution", processes are limited to allopatric and sympatric speciation, reproductive isolating mechanisms, the role natural selection, convergence, divergence, adaptive radiation, co-evolution, punctuationism and gradualism.

Given that the national qualification standards effectively control what students will actually study and what is actually examined, the two Level 3 standards specifically related to evolution as 'patterns and processes', and 'human biological and cultural evolution, the curriculum is well covered by these standards. In 2006, there were a total of 149,927 student results gaining credit (www.nzqa) in national qualifications for all biology standards (See Chapter 8 for candidate number details) but the key point is that although evolution, as a guiding principle of biology, is recognised and acknowledged in the curriculum, relatively few students actually end up gaining credits in this subject and thus gaining a more sophisticated scientific understanding of evolutionary processes. It is not surprising that myths and legends are often perpetuated in society with regard to the fact of biological evolution.

9.2.2 What sort of 'Evolution' Questions are Asked in National Exams?

This section will focus on achievement standards. Achievement standard assessment questions in NZ evolved from original competency based standards (called unit standards) in an attempt to recognise the different levels of achievement that students perform at in an examination. Achievement standards were also developed to assess different levels of understanding through the use of a broad application of Bloom's taxonomy of descriptive, explanatory and discursive style questions (see Chapter 9 for more details). Questions requiring discussion are intended to assess a higher level of thinking and understanding. A balance of each level of question is generally achieved. Unit standards on the other hand are either passed or failed based on performance (answers) which conform to prerequisite criteria (see Chapter 9 for details).

Questions from the 2007 Examination on Evolution from Level 2 (Year 12) AS 90459 "Genetic variation and change" national external examination.

Note that most questions have resource information that is not reproduced here. Complete downloads are available on the NZQA website at http://www.nzqa.govt.nz.

1 ***"Discuss*** *how the* ***processes*** *involved in meiosis can contribute to genetic variation.*

2. *Define the term* ***gene pool****.*

3. *Explain how new alleles can enter and become established in a population.*

4. *Two processes that could be responsible for the genetic change in the New Zealand population of blowflies are* ***genetic drift*** *and* ***natural selection.***
   Explain *how* ***each*** *of these two processes works to change the allele frequencies of the populations.*

5. ***Discuss*** *why the arrival of the blowfly in New Zealand is considered to be an example of the* ***Founder Effect*** *rather than a* ***Population Bottleneck".***

Forty minutes are recommended for this examination and as can be seen, questions at this curriculum Level, although accurately constrained by the standard requirements on evolution, focus on sources of genetic variation and genetic change but do not address speciation mechanisms or evidence for evolution. The fossil record (paleontology and paleoecology) and its connection to geological time and environmental change is not part of the curriculum at this level and consequently students are not exposed to the conceptual connections between biological evolution and geology. Achievement standards select aspects of the curriculum for national qualification assessment tasks. It should be pointed out that unit standard questions are internally set by the classroom teacher (with a measure of NZQA moderation), and therefore students (nationally) sit different questions covering the same unit standard criteria. Comparisons are therefore impossible. There are two discuss questions, two explanatory and one descriptive. However, questions that are discursive and explanatory commonly ‘scaffold’ down to enable students to demonstrate the depth of their understanding. It is clear that connecting the fossil record and geological events for this assessment standard is not what biologists consider to be ‘biology’. Students at this level are expected to demonstrate understanding of the mechanisms for genetic variation within a populational context but it remains disconnected to geological and paleoecological events.

Questions from the 2007 Examination on Evolution from Level 3 (Year 13) AS 90717 “Patterns of Evolution” national external examination.

1(a) *"Name and describe the **pattern of evolution** shown by the relationship between this nectar bat and its food plant.*

(b) *Explain the role of **natural selection** in the evolution of the features shown by the bat and its food plant.*

(c) *Discuss how **geological history** has affected the adaptive radiation and distribution of Celatoblatta species in the South Island.*

(d) *The phylogenetic tree suggests that there are two distinct populations of C. montana on Mt Taylor (in the Central region).*
Explain the significance of these two populations.

2(a) *Use the information from the table to describe how these different Libertia species have evolved.*

(b) *Explain how L. paniculata (2n = 76) could have evolved from L. puchella. L. peregrinans, from **inland Nelson**, has a different chromosome number, and is different in appearance, from other populations of this species.*

(c) *Explain how this inland Nelson population could have evolved, AND give evidence from the table on the opposite page to support your answer.*

(d) *Explain how the data in the above diagram support the statement that “indigobird evolution shows adaptive radiation and punctuated equilibrium”.*

(e) *Indigobird speciation appears to be sympatric.*
Discuss how new indigobird species could evolve. You should include the role of song and other isolating mechanisms in your answer".

Forty minutes are also recommended for this examination. This standard focuses on speciation and modes of evolution with question 1c in particular, requiring students to have knowledge and understanding of geological isolating mechanisms for species such as glaciation imprinted on a background of plate tectonic activity. It is only in this final secondary school year standard that students begin to come to grips with organismal evolution connected to geological events and time. Unfortunately the fossil record misses out again not only within the assessment standard but also within the curriculum. The average percentage of results gaining credit ('passes') in this standard was around 50% (See chapter 8 figure 8.8). With 50% of those who enter biology AS 90717 failing this standard the number of students leaving secondary school with adequate understanding of the patterns of evolution is very low. It is not surprising then that the general population is ignorant of the facts of biological evolutionary patterns and mechanisms. Few will go on to tertiary studies and specialise in evolutionary theory and mechanisms because few who take this examination go on to tertiary studies and specialize in paleontology.

Questions from the 2007 Examination on Evolution from Level 3 (Year 13, 17/18 year olds) AS 90719 "Trends in Human Evolution" external examination.

1(a) *"The foot of the chimpanzee is different from that of hominins.*
- *(I) Describe ONE skeletal feature of the foot of the chimpanzee that differs from that of a hominin.*
- *(ii) Explain how this difference is linked to bipedalism.*

(b) *Describe **two** differences between the chimpanzee and hominin **pelvic girdles** that are related to bipedalism.*

(c) *Explain the **relationship** between the shape of the pelvic girdle and the ability to walk bipedally.*

(d) *Explain **why** the pelvic inlet is larger in Homo sapiens than in H. erectus.*

(e) *The width of the pelvic inlet is related to locomotion. H. erectus had a narrower pelvic inlet than modern humans, and walked more efficiently. Discuss how conflicting selection pressures have acted on the evolution of the pelvic inlet in modern humans.*

2(a) *Explain TWO **benefits** to Homo erectus of using fire.*

(b) *Describe the **trend** in brain volume shown in this graph.*

(c) *Discuss the **relationship** between cranial capacity and cultural evolution in hominins.*
*Support your answer with reference to ONE aspect of cultural evolution in **named hominin species**. (Aspects of cultural evolution include, but are not limited to: tool use and manufacture; art; language; domestication of plants and animals.)*

Most scientists agree that Homo erectus was the first hominin species to migrate out of Africa. Probable migration routes are shown below. (Diagram not included here).

3(a) Describe the relative speed at which this migration took place AND give evidence to support your answer.
Recent research suggests that climate change is related to the migration out of Africa of various hominin species.

*(b) Discuss the impact a change in climate from wet tropical to cooler drier conditions would have on migration out of Africa by **H. erectus**.*
(c) Discuss what the ability to make a boat or raft indicates about the behaviour and cultural evolution of Homo erectus".

In this standard, with a recommended forty minutes for completion, focus is on skeletal comparisons of hominoids and hominins (ankle, pelvis and bipedalism), cultural trends, cranial capacity and issues surrounding migration and dispersal of hominins (humans) out of Africa. Hominoids include humans and the great apes. Fossil lineages and localities are not part of this assessment standard, and significantly, there is no connection with geological time and events. It is noteworthy that in the Australian (New South Wales) HSC Earth and Environmental studies course which is at the same level as New Zealand's Year 13, there is considerable content looking at geological history and environments through time but still divorced from biology and evolution (Pohl, 2002). In NZ, the only places these topics can be studied and assessed for national qualifications is in unit standards, and vey few schools offer this topic and then there are very low numbers of students enrolled. In effect, learning about earth history, paleontology and paleoecology in an evolutionary biological context is extremely unusual and generally cursory in NZ schools.

Chapter 10 GeoVAT Result Tables

Table 10.2. NZ Secondary teacher trainee response comparison for Section A question 1 (True/false ideas about fossils).

Question statements GeoVAT Q.1.	**AUB %**	**UC %**
1. Fossils grow from seeds in rocks	100% F	100% F
2. Fossils are the failed creations of God	100% F	100% F
3. Fossils are tricks of the Devil	100% F	100% F
4. Fossils are just accidents of nature	79% F	87% F
5. Fossils are the preserved parts of once living things	84% T	100% T
6. Fossils are the preserved parts of extinct things only	79% F	93% F
7. Fossils are important and interesting	95% T	100% T
8. Fossils support the theory and fact of evolution	74% T	87% T
9. Charles Darwin was the first to think of evolution	26% F	73% F
10. Humans have evolved from apes	42% T	67% T
11. Oldest known fossils are about 3.4 billion years old	53% T	60% T
12. A scientific theory is just a guess	100% F	73% F
13. Birds are descendants of dinosaurs	37% T	40% T
14. The Earth was made in six days	100% F	80% F
15. All living things share the same basic DNA coding system	26% T	60% T
16. New species appear suddenly	26% T	40% T
17. Evolution is slow change from one species to another	95% T	73% T
18. Scientific method only involves controlled tests	11% T	73% T

Table 10.3. Comparison of AC Year 12 with secondary teacher trainees for GeoVAT

Question (n = 21 for AC Y12)	AC Y12	UB	UC
1. Fossils grow from seeds in rocks	100% F	100% F	100% F
2. Fossils are the failed creations of God	95% F	100% F	100% F
3. Fossils are tricks of the Devil	100% F	100% F	100% F
4. Fossils are just accidents of nature	86% F	79% F	87% F
5. Fossils are the preserved parts of once living things	100% T	84% T	100% T
6. Fossils are the preserved parts of extinct things only	86% F	79% F	93% F
7. Fossils are important and interesting	95% T	95% T	100% T
8. Fossils support the theory and fact of evolution	95% T	74% T	87% T
9. Charles Darwin was the first to think of evolution	52% F	26% F	73% F
10. Humans have evolved from apes	62% T	42% T	67% T
11. Oldest known fossils are about 3.4 billion years old	90% T	53% T	60% T
12. A scientific theory is just a guess	67% F	100% F	73% F
13. Birds are descendants of dinosaurs	62% T	37% T	40% T
14. The Earth was made in six days	81% F	100% F	80% F
15. All living things share the same basic DNA coding system	52% T	26% T	60% T
16. New species appear suddenly	33% T	26% T	40% T
17. Evolution is slow change from one species to another	81% T	95% T	73% T
18. Scientific method only involves controlled tests	43% T	11% T	73% T

Table 10.4. Comparison of high school age cohorts for ideas about fossils.

QUESTION 1 **Section A GeoVAT** **(T=True. F = False)**	**AC** **Y13** **(n = 39)**	**AC** **Y12** **(n=13)**	**AC** **Y11** **(n=25)**	**AC** **Y9** **(n=13)**	**IS** **Y12** **(n = 10)**	**IS** **Y13** **(n = 8)**
1. Fossils are from seeds in rocks	100% F	100%F	100%F	100% F	100% F	100%F
2. Fossils are failed creations	100%F	95%F	96%F	100% F	70%F	100%F
3. Fossils are tricks of the devil	100% F	100%F	100%F	100% F	100%F	100%F
4. Fossils are accidents of nature	89% F	86%F	76%F	79% F	100%F	100%F
5.Fossils are preserved remains	95% T	100%T	96%T	86%T	100%T	100%T
6. Fossils are preserved extinct org.	87% F	86%F	68%F	67%F	90%F	100%F
7. Fossils are important & interest.	95% T	95%T	84%T	93%T	80%T	100%T
8. Supports the fact of evolution.	90%T	95%T	84%T	93%T	80%T	100%T
9. Darwin first for evolution.	62% F	52%F	36%F	21%F	20%F	13%F
10. Humans are evolved from apes.	74% T	62%T	80%T	79%T	70%T	62%T
11. 3.4 bya oldest fossils.	74% T	90%T	80%T	64%T	50%T	87%T
12. Sc. theory is a guess.	69% F	67%F	68%F	79%F	60%F	38%F
13. Birds are from dinosaurs.	44% T	62%T	64%T	33%T	50%T	75%T
14. Earth was made in 6 days.	77% F	81%F	84%F	86%F	50%F	100%F
15. Common DNA code.	38% T	52%T	48%T	43%T	70%T	62%T
16. Punctuationism.	51% T	33%T	52%T	29%T	50%T	62%T
17. Gradualism.	85% T	81%T	72%T	93%T	100%T	87%T
18. Sc. method = c. testing.	69% T	43%T	60%T	50%T	50%T	87%T

Table 10.5. Years 12 and 13 comparison with AUB and UC secondary teacher trainees for Question 1 Section A: Ideas about Fossils.

Question (n = 39 for AC Year 13) (T = true)	AC Y13	AC Y12	UB Sec trainees	UC Sec trainees
1. Fossils grow from seeds in rocks	100% F	100% F	100% F	100% F
2. Fossils are the failed creations of God	100%F	95% F	100% F	100% F
3. Fossils are tricks of the Devil	100% F	100% F	100% F	100% F
4. Fossils are just accidents of nature	89% F	86% F	79% F	87% F
5. Fossils are the preserved parts of once living things	95% T	100% T	84% T	100% T
6. Fossils are the preserved parts of extinct things only	87% F	86% F	79% F	93% F
7. Fossils are important and interesting	95% T	95% T	95% T	100% T
8. Fossils support the theory and fact of evolution	90%T	95% T	74% T	87% T
9. Charles Darwin was the first to think of evolution	62% F	52% F	26% F	73% F
10. Humans have evolved from apes	74% T	62% T	42% T	67% T
11. Oldest known fossils are about 3.4 billion years old	74% T	90% T	53% T	60% T
12. A scientific theory is just a guess	69% F	67% F	100% F	73% F
13. Birds are descendants of dinosaurs	44% T	62% T	37% T	40% T
14. The Earth was made in six days	77% F	81% F	100% F	80% F
15. All living things share the same basic DNA coding system	38% T	52%	26% T	60% T
16. New species appear suddenly	51% T	33% T	26% T	40% T
17. Evolution is slow change from one species to another	85% T	81% T	95% T	73% T
18. Scientific method only involves controlled tests	69% T	43% T	11% T	73% T

Table 10.6. Other suggestions in explanation for the absence of fossils.

Explanation for absence of fossils	**Conceptualisation Interpretation**
"Insufficient time to **form** fossils"	Unfavourable environment for fossilisation. Misconception of the link with time.
"The rock was not old enough to form fossils"	Misconception of fossilisation processes.
"Fossils were destroyed by metamorphism"	Misconception of rock types.
"There were no animals around for fossils to form"	A reasonable conception that there was nothing to be fossilised but no link with geological process.
"Bones decomposed before fossilisation could occur"	Unfavourable environment for fossilisation. Misconception of formation of fossils.
"A landslide removed the fossils"	Misconception that fossils are found within rock and not separate entities with different histories.
"All decayed and were ground away"	Misconception of fossilisation processes.
"Rock was too hard to form fossils"	Misconception of fossilisation processes.

Table 10.7. Comparison of Year 11 responses to Section A question 1.

QUESTION 1 **Section A GeoVAT**	**AC** **Y13**	**AC** **Y12**	**AC** **Y11**	**AC** **Y9**	**UB** **PT**	**UC** **PT**
1. Fossils are from seeds in rocks	100% F	100%F	100%F	100% F	100%F	100% F
2. Fossils are failed creations	100%F	95%F	96%F	100% F	100%F	100% F
3. Fossils are tricks of the devil	100% F	100%F	100%F	100% F	100%F	100% F
4. Fossils are accidents of nature	89% F	86%F	76%F	79% F	79%F	87% F
5.Fossils are preserved remains	95% T	100%T	96%T	86%T	84%T	100% T
6. Fossils are preserved extinct org.	87% F	86%F	68%F	67%F	79%F	93% F
7. Fossils are important & interest.	95% T	95%T	84%T	93%T	95%T	100% T
8. Supports the fact of evolution.	90%T	95%T	84%T	93%T	74%T	87% T
9. Darwin first for evolution.	62% F	52%F	36%F	21%F	26%F	73% F
10. Humans are evolved from apes.	74% T	62%T	80%T	79%T	42%T	67% T
11. 3.4 bya oldest fossils.	74% T	90%T	80%T	64%T	53%T	60% T
12. Sc. theory is a guess.	69% F	67%F	68%F	79%F	100%F	73% F
13. Birds are from dinosaurs.	44% T	62%T	64%T	33%T	37%T	40% T
14. Earth was made in 6 days.	77% F	81%F	84%F	86%F	100%F	80% F
15. Common DNA code.	38% T	52%T	48%T	43%T	26%T	60% T
16. Punctuationism.	51% T	33%T	52%T	29%T	26%T	40% T
17. Gradualism.	85% T	81%T	72%T	93%T	95%T	73% T
18. Sc. method = c. testing.	69% T	43%T	60%T	50%T	11%T	73% T

Table 10.8. Comparison of Year 9 responses to Section A question 1.

Question (n = 39 for AC Year 13) (T = true)	**AC Y13**	**AC Y12**	**UB PT**	**UC PT**	**AC Y9**
1. Fossils grow from seeds in rocks	100% F	100%F	100%F	100% F	100% F
2. Fossils are the failed creations of God	100%F	95%F	100%F	100% F	100% F
3. Fossils are tricks of the Devil	100% F	100%F	100%F	100% F	100% F
4. Fossils are just accidents of nature	89% F	86%F	79%F	87% F	79% F
5. Fossils are the preserved parts of once living things	95% T	100%T	84%T	100% T	86%T
6. Fossils are the preserved parts of extinct things only	87% F	86%F	79%F	93% F	67%F
7. Fossils are important and interesting	95% T	95%T	95%T	100% T	93%T
8. Fossils support the theory and fact of evolution	90%T	95%T	74%T	87% T	93%T
9. Charles Darwin was the first to think of evolution	62% F	52%F	26%F	73% F	21%F
10. Humans have evolved from apes	74% T	62%T	42%T	67% T	79%T
11. Oldest known fossils are about 3.4 billion years old	74% T	90%T	53%T	60% T	64%T
12. A scientific theory is just a guess	69% F	67%F	100%F	73% F	79%F
13. Birds are descendants of dinosaurs	44% T	62%T	37%T	40% T	33%T
14. The Earth was made in six days	77% F	81%F	100%F	80% F	86%F
15. All living things share the same basic DNA coding system	38% T	52%T	26%T	60% T	43%T
16. New species appear suddenly	51% T	33%T	26%T	40% T	29%T
17. Evolution is slow change from one species to another	85% T	81%T	95%T	73% T	93%T
18. Scientific method only involves controlled tests	69% T	43%T	11%T	73% T	50%T

Figure 10.3. AUB primary school trainee responses to GeoVAT Question 1.

American Univ. of Beirut (AUB)

(Average age of 19 years 5months) **Responses 1 = true 0 = False**

	Student Response (n = 19)																				
Section A, Question 1: Ideas about Fossils	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	Response	Expected
1. Fossils grow from seeds in rocks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100% F	F
2. Fossils are the failed creations of god	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100% F	F
3. Fossils are tricks of the Devil	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100% F	F
4. Fossils are just accidents of nature	0	0	1	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	79% F	F
5. Fossils are the preserved parts of once living things	1	1	1	1	1	1	1	1	0	1	1	0	1	1	0	1	1	1	1	84% T	T
6. Fossils are the preserved parts of extinct things only	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	1	0	0	0	79% F	F
7. Fossils are important and interesting	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	95% T	T
8. Fossils support the theory and fact of evolution	1	1	1	1	1	1	1	0	1	1	1	0	0	1	1	1	0	1	0	74% T	T
9. Charles Darwin was the first to think of evolution	1	1	0	1	1	1	1	1	1	1	1	0	0	1	1	1	0	1	0	26% F	F
10. Humans have evolved from apes	1	1	0	1	1	0	0	1	0	0	0	1	0	0	1	0	0	0	1	42% T	T
11. Oldest known fossils are about 3.4 billion years old	1	1	0	1	0	1	1	1	1	1	0	0	0	0	0	0	1	1	0	53% T	T
12. A scientific theory is just a guess	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100% F	F
13. Birds are descendants of dinosaurs	0	0	0	0	0	1	1	1	0	0	0	0	0	1	1	1	1	0	0	37% T	T
14. The Earth was made in six days	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100% F	F
15. All living things share the same basic DNA coding system	0	0	0	0	0	0	1	0	0	1	0	0	0	1	1	0	0	1	0	26% T	T
16. New species appear suddenly	0	0	0	0	0	0	1	0	0	1	0	0	0	1	1	0	0	1	0	26% T	T
17. Evolution is slow change from one species to another	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	95% T	T
18. Scientific method only involves controlled tests	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	89% F	F

Key to colours

Grey = General agreement with expected

Red = Significant disagreement

Blue = agreement

Figure 10. 6. AUB primary school trainee responses to Section B, Q 3. Fossils and time.
(No's refer to number of responses per Q).

Red = Ranked Acceptable Age
(n = 7 to 14)

Time Category

Q. No.	Question (After Trend, 2001)	A	B	C	D	E	F	G	H	I	J	% correct	Acceptable Age
4	Development of plate tectonic theory	0	2	0	1	0	1	0	2	0	1	0	AD 1960
11	Extinction of the woolly mammoths	0	0	0	0	0	0	5	2	1	0	0	12,000 ya
18	Appearance of first humans	2	0	0	0	0	0	0	2	0	2	0	2 mya
6	The Ice Age	0	3	1	2	0	1	0	1	1	0	0	2.4 mya
5	Extinction of large dinosaurs	1	0	4	3	1	2	0	2	1	0	14	65 mya
15	Appearance of the first birds	0	0	3	0	0	1	0	2	1	2	0	200 mya
16	Appearance of the first dinosaurs	1	2	2	0	0	0	2	2	1	0	20	220mya
8	Extinction of the trilobites	2	1	3	0	0	0	2	0	0	2	20	225 mya
20	Beginning of the Atlantic Ocean	0	0	0	0	0	1	0	1	2	2	0	230 mya
21	Appearance of the first trees	0	0	0	0	0	0	0	4	3	1	0	380 mya
7	First appearance of land animals	0	0	0	0	3	3	0	0	2	2	0	400 mya
1	First fish to appear	2	0	0	0	1	2	3	2	1	3	21	500mya
22	Oldest rocks in your country	0	0	0	1	0	0	0	3	3	2	0	520 mya
17	First life forms with shells or bones	1	2	0	1	0	1	0	3	1	0	0	560 mya
13	First life forms on Earth	1	1	0	0	1	1	0	3	2	1	30	3.5 bya
19	First volcanoes	1	0	1	1	2	0	1	4	0	0	40	4.1bya
10	First rocks on Earth	0	5	2	0	0	0	0	2	0	1	20	4 bya
2	Formation of the Earth's crust	0	0	1	0	0	0	0	3	4	3	27	4 bya
12	Formation of the Moon	2	0	0	0	0	0	0	3	0	4	33	4.3 bya
9	Formation of the Sun	0	1	0	0	0	1	0	1	0	5	0	4.6 bya
3	Formation of the Earth	3	0	0	0	0	0	0	3	1	4	9	4.6 bya
24	Formation of the Milky Way galaxy	2	1	0	0	0	0	0	2	0	4	0	10 bya
23	Beginning of time	0	1	1	0	0	0	0	0	1	6	11	13 bya
14	Big Bang formation of the Universe	0	1	2	0	0	0	0	0	2	5	20	13 bya

Key

Years ago with age bands

- A =<100y
- B =100 -1000
- C = 1000 -100,000
- D = 100,000 -1 million
- E = 1 million -10 million
- F = 10 million -100 million
- G = 100 million -1billion
- H = 1billion - 5 billion
- I = 5b -1million million
- J = >1million million

1 billion = 1000 million
bya = billion years ago
Red = acceptable geological age

Figure 10.7. UC Secondary teacher trainee responses to GeoVAT Question 1

(Average age of 22 years 6 months) **Responses 1 = true 0 = False**

	Student Response (n = 15)																
Section A, Question 1: Ideas about Fossils	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	Response	Expected
1. Fossils grow from seeds in rocks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100% F	F
2. Fossils are the failed creations of God	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100% F	F
3. Fossils are tricks of the Devil	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100% F	F
4. Fossils are just accidents of nature	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	87% F	F
5. Fossils are the preserved parts of once living things	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100% T	T
6. Fossils are the preserved parts of extinct things only	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	93% F	F
7. Fossils are important and interesting	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100% T	T
8. Fossils support the theory and fact of evolution	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	87% T	T
9. Charles Darwin was the first to think of evolution	0	0	0	0	0	0	1	1	0	0	1	0	0	0	1	73% F	F
10. Humans have evolved from apes	0	0	1	1	1	0	1	1	1	1	1	0	1	0	1	33% F	T
11. Oldest known fossils are about 3.4 billion years old	0	1	0	1	1	1	0	1	0	1	0	1	0	1	1	40% F	T
12. A scientific theory is just a guess	0	0	0	1	0	0	0	0	1	0	1	0	0	0	1	73% F	F
13. Birds are descendants of dinosaurs	0	1	1	0	0	1	0	0	1	0	0	1	0	0	1	60% F	T
14. The Earth was made in six days	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	80% F	F
15. All living things share the same basic DNA coding system	1	1	0	0	1	1	1	1	0	0	1	1	0	0	1	40% F	T
16. New species appear suddenly	0	1	0	1	0	0	1	0	0	0	1	1	0	0	1	60% F	T
17. Evolution is slow change from one species to another	0	1	0	0	1	1	1	1	1	0	1	1	1	1	1	27% F	T
18. Scientific method only involves controlled tests	1	1	0	1	1	1	1	0	1	1	1	1	0	1	0	27% F	F

Key to colours

Grey = General agreement with expected

Red = Significant disagreement

Blue = agreement

Figure 10.8. UC secondary school trainee responses to Section B , Q3 results: Fossils and Time.

UC secondary school trainees (No's refer to number of responses per Q).

Red = Ranked Acceptable Age

(n = 9)

Time Category

Q. No.	Question (After Trend, 2001)	A	B	C	D	E	F	G	H	I	J	% correct	Acceptable Age
4	Development of plate tectonic theory	8	0	0	0	0	0	0	0	0	0	100	AD 1960
11	Extinction of the woolly mammoths	0	0	2	0	2	2	1	0	0	0	25	12,000 ya
18	Appearance of first humans	0	0	2	3	0	0	0	0	0	0	0	2 mya
6	The Ice Age	0	0	4	0	1	3	0	0	0	0	14	2.4 mya
5	Extinction of large dinosaurs	0	0	0	0	1	3	0	0	0	0	75	65 mya
15	Appearance of the first birds	0	0	0	0	2	0	3	0	0	0	60	200 mya
16	Appearance of the first dinosaurs	0	0	0	0	0	1	4	0	0	0	80	220mya
8	Extinction of the trilobites	0	0	0	0	0	3	2	0	0	0	40	225 mya
20	Beginning of the Atlantic Ocean	0	0	0	0	1	0	0	2	0	0	0	230 mya
21	Appearance of the first trees	0	0	0	0	1	0	2	0	0	0	66	380 mya
7	First appearance of land animals	0	0	0	0	1	0	3	1	0	0	60	400 mya
1	First fish to appear	0	0	0	0	0	3	2	0	0	0	40	500mya
22	Oldest rocks in your country	0	0	0	0	0	1	0	2	2	0	0	520 mya
17	First life forms with shells or bones	0	0	0	0	0	0	1	2	0	0	50	560 mya
13	First life forms on Earth	0	0	0	0	0	0	3	2	0	0	40	3.5 bya
19	First volcanoes	0	0	0	0	0	0	0	3	0	0	100	4.1bya
10	First rocks on Earth	0	0	0	0	1	0	1	2	3	0	29	4 bya
2	Formation of the Earth's crust	0	0	0	0	1	0	0	3	3	0	43	4 bya
12	Formation of the Moon	0	0	0	0	1	0	0	2	0	0	66	4.3 bya
9	Formation of the Sun	0	0	0	0	0	0	0	1	4	4	11	4.6 bya
3	Formation of the Earth	0	0	0	0	1	0	0	4	3	1	50	4.6 bya
24	Formation of the Milky Way galaxy	0	0	0	0	0	0	0	0	0	5	0	10 bya
23	Beginning of time	0	0	0	0	0	0	0	0	0	5	0	13 bya
	Big Bang formation of the Universe	0	0	0	0	0	0	0	0	3	4	75	13 bya

Key

Years ago with age bands

A =<100y
B =100 -1000
C = 1000 -100,000
D = 100,000 -1 million
E = 1 million -10 million
F = 10 million -100 million
G = 100 million -1billion
H = 1billion - 5 billion
I = 5b -1million million
J = >1million million

mya = million years ago
1 billion = 1000 million years
bya = billion years ago
Red = acceptable geological age

Fossils and Time: GeoVAT Section B, Question 3.

	Time Category (Red is correct response)													
Q	A	B	C	D	E	F	G	H	I	J	n	% over estimate	% under estimate	% Correct
4	9	5	2					1	2		19	53	0	47
11		1	1	5	8	1		1		1	18	89	6	6
18			4	5	3	3	3			1	19	37	47	16
6			3	2	5	3	3	1	1		18	44	28	33
5		1	1	3	3	6	3	2	1		20	30	40	30
15			3		2	5	2	3	2		17	29	59	12
16			2	1		2	2	6	4		17	59	29	12
8	1		1	2	2	2	5	1	1		15	13	53	33
20			1	3	2	1	1	5	3	3	19	58	37	5
21			1	1	2	5	1	7	1	1	19	47	47	5
7			1		2	5	3	3	3	1	18	39	44	17
1			2	2	1		5	5	2	2	19	47	26	26
22		1	1	4	1	2	3	1	2	2	17	29	53	17
17			1	1	2	4	4	2	5		19	37	42	21
13				1	2	3	2	6	5	3	22	27	36	27
19				1	2	5	2	2	6	2	20	40	50	10
10			1	1		1	1	5	4	5	18	50	22	28
2			1			1		5	4	7	18	61	11	28
12			1			4		5	1	9	20	50	25	25
9							1		4	14	19	95	5	0
3			1			1		4	1	12	19	68	10	21
24						1		1	4	13	19	68	10	21
23								2		17	19	89	10	0
14					1	1		1	4	11	18	61	17	22
									Mean %			52	29	18

Figure 10.11. AC Year 12 distribution of responses for GeoVAT question 3.

	Time Category (Red is a correct response)													
Q	A	B	C	D	E	F	G	H	I	J	*n*	% over estimate	% under estimate	% Correct
4	1	8	2								*11*	91	0	9
11			4		1	3	1	1			*10*	60	0	40
18		2	5	3	1						*11*	0	91	9
6			3	2	3	1	1		1		*11*	45	27	27
5			2	3	4	1	2				*12*	17	75	8
15		1	2		3	2	2	1			*11*	9	72	8
16		2			1	3	1	3	1		*11*	9	54	9
8	1		2			3	2	2	1		*11*	18	54	18
20			2	1	2	1	1	1	3		*11*	8	54	9
21		1			2	1	3	1	1	1	*10*	30	40	30
7		1	3		2	1	4	1			*12*	17	58	33
1		1	2	1	4	1	2	1			*12*	17	75	17
22		2	3		2		1	3	1	1	*13*	35	54	8
17			1		3	1	1	3	1	1	*11*	45	46	9
13				2	2	2		3	1		*10*	10	60	30
19				1	1	1		2	2	4	*11*	54	27	8
10		1	1		1	2		2	4		*11*	36	45	8
2					1			1	4	6	*12*	83	8	8
12		1		1				1	6	3	*12*	5	17	8
9						1				10	*11*	91	9	0
3					1			1	1	4	*7*	71	14	14
24						2			3	6	*11*	54	18	27
23								1	5	6	*12*	50	8	42
14								1		11	*12*	92	8	0
									Y 13 Mean			41	38	14
									Y12 Mean			52	29	18

Figure 10.14. AC Year 13 distribution of responses for GeoVAT question 3.

	Time Category (red is a correct response)											AC Year 9 results		
Q'n	A	B	C	D	E	F	G	H	I	J	*n*	% over estimate	% under estimate	% Correct
4	1	5	5	1				1			*13*	92	0	8
11				2	2	2	6	1			*13*	100	0	0
18			4	5	1	1	1		1		*13*	23	69	8
6			1	5	1		4		1	1	*13*	46	46	8
5			2	3		2	4	1	1		*13*	46	38	16
15			2	2	2	1	4	2			*13*	15	53	32
16					2	2	1	7		1	*13*	61	31	8
8		1	2	4	2	2			2		*13*	15	85	0
20		1	1	1		5	1	2		2	*13*	31	60	8
21			1	1	1	1	1		8		*13*	62	30	8
7			4		3		1	4		1	*13*	38	54	8
1				2	1		3	4	3		*13*	53	23	24
22		1	1	1	3	6	1				*13*	0	92	8
17			1	2	1		3	6			*13*	46	31	23
13		1	1		1		1	2	5	2	*13*	69	23	8
19			1	1	4		3	2	1	1	*13*	15	69	16
10					1	1	1	2	7	1	*13*	61	23	16
2								2	6	5	*13*	85	0	15
12				1				6	1	5	*13*	46	8	46
9									2	11	*13*	100	0	0
3					1			1	1	10	*13*	85	7	8
24								1	3	9	*13*	68	8	24
23					1		1		1	10	*13*	77	15	8
14		1		1					1	10	*13*	77	15	8
											Y 9 Mean	**57%**	**33%**	**10%**
											Y 13 Mean	41%	38%	14%
											Y12 Mean	52%	29%	18%
											Combined AC Means	49%	33%	15%

KEY to Age Categories

A = <100y **B** = 100 – 1000y **C** = 1000 – 100,000y
D = 100,000 – 1mya **E** = 1mya – 10mya **G** = 100mya – 1bya
H = 1bya – 5bya **I** = 5bya – 1mmya **J** = > 1mmya

Figure 10.16. Distribution of responses for GeoVAT question 3 for AC Year 9 (n = 13).

	Time Category (red is a correct response)													
Q'n	A	B	C	D	E	F	G	H	I	J	*n*	% over estimate	% under estimate	% Correct
4	5	5		2	2	1					*15*	67	0	33
11			3	2	1	3	1	1	1	2	*14*	79	0	21
18		2	2	9	1						*14*	0	93	7
6			1	4	2		2	2		2	*13*	46	39	15
5			2	4	2	2	2			2	*14*	57	29	14
15				3	3	2	2			5	*15*	33	54	13
16						5	1	1	7		*14*	57	36	7
8	1				8	1	0			4	*14*	29	71	0
20			2		2	3	2	1	3		*13*	31	54	15
21			3	4			1	7			*15*	46	47	7
7			2	1	1	4	2	2	2		*14*	29	57	14
1		2		1	1	4	4			2	*14*	14	53	29
22			1	1		2		8	1	1	*14*	71	29	0
17				1	2	1	2	5	1		*12*	50	33	17
13		1		4			1	8			*14*	0	43	57
19			2	5		1		0	4	2	*14*	43	57	0
10		1	1	1		3	1	3	1	2	*13*	54	23	23
2						2	1	5	3	4	*15*	47	20	33
12			1	2			3	4		5	*15*	33	40	27
9	1					2	5	2		4	*14*	46	50	14
3						1		2	7	3	*14*	71	15	14
24						1	2	1	0	11	*15*	73	27	0
23				2					1	12	*15*	73	20	7
14		1		1	2			2	3	6	*15*	40	39	21
									Mean			44	38	14

Figure 10.18. Distribution of responses for GeoVAT question 3 for AC Year 11 (n = 25).

	Time Category (red is a correct response)													
Q	A	B	C	D	E	F	G	H	I	J	*n*	% over estimate	% under estimate	% Correct
4	3	3			1		1				*8*	63	0	37
11	1		2					2	2		*7*	57	14	29
18			1	1	1			1	1		*5*	40	40	20
6		1	4		0		1		1	1	*8*	38	62	0
5	3					4	1			1	*9*	22	33	45
15					1	1	4				*6*	0	33	27
16		1			1		4				*6*	0	33	67
8	1						4	1			*6*	17	17	67
20					1	1	2				*4*	0	50	50
21		1					1	1			*3*	33	33	33
7	1					2	4				*7*	0	43	57
1				1	1	1	1	2	2		*8*	50	38	13
22							0	1		5	*6*	100	0	0
17			2	1			0				*3*	0	100	0
13			2				1	0		4	*7*	57	43	0
19						1		0	1	1	*3*	66	33	0
10			2					1	1	1	*5*	66	33	20
2	1							4	2		*7*	29	14	57
12	1							2		2	*5*	40	20	40
9		1				2		0	1	4	*8*	63	38	0
3	1			1				0	5	2	*9*	78	22	0
24							1	2	0	3	*6*	50	50	0
23									1	5	*6*	83	0	17
14	1		1						0	4	*6*	67	33	0
									Mean			42	33	24

Figure 10.21. Distribution of responses for question 3 for IS Grade 11.

	Time Category (red is a correct response)										N = 10			
Q'n	A	B	C	D	E	F	G	H	I	J	*n*	% over estimate	% under estimate	% Correct
4	6	2	2								*9*	44	0	56
11		2	2		1			1			*6*	33	34	33
18			2	1	4				1		*8*	12	38	50
6		1		1	2		1			1	*6*	33	34	33
5			2	1	1	2	2				*8*	25	50	25
15		1	2		3		0			1	*7*	14	86	0
16		1	2			1	3	1			*8*	12	50	38
8				1		2	4	1			*8*	12	38	50
20					2	3	1	1			*7*	14	72	14
21		1		1	2	4	1	1			*10*	10	80	10
7				1	4	2	0				*7*	0	100	0
1					1	1	1	2		2	*7*	57	29	14
22					1	1	4		1		*7*	14	29	57
17			2		1	1	1	1			*6*	33	50	17
13					1		2	3	2	1	*9*	33	34	33
19				1		1	4	0	1		*7*	14	86	0
10		1		1		1	1	1	1		*6*	16	67	17
2					1	1	1	2		2	*7*	29	42	29
12					1			4		1	*6*	16	16	67
9			1					2	2	2	*7*	57	14	29
3							1	3	2	1	*7*	43	14	43
24								3	1	5	*9*	56	33	11
23			1	1	1			2	1	4	*10*	40	50	10
14			1					2	2	2	*7*	29	42	14
									Mean			27	45	28

Figure 10.22. Distribution of responses for question 3 for IS Grade 12 (n = 10)

Fossils and Time: Section B, Question 3 GeoVAT
Distribution of responses per question for UC Second Year (mean age 22y)

	Time Category (red is a correct response)													
Q	A	B	C	D	E	F	G	H	I	J	*n*	% over estimate	% under estimate	% Correct
4	8										*8*	0	0	100
11			4	1	2	1					*8*	50	0	50
18			2	3	2			1			*8*	13	63	25
6		1	5	1	1						*8*	0	88	13
5			1		2	5					*8*	0	38	63
15			1	1	2	4					*8*	0	100	0
16				1		2	5				*8*	0	38	63
8				3	1		4				*8*	0	50	50
20			1		1	4	1	1			*8*	13	75	13
21			1		1	2	2		2		*8*	25	50	25
7				3		1	4				*8*	0	50	50
1				1	1	1	4	1			*8*	13	38	50
22			1		2	1	3	1			*8*	13	50	38
17			1	1		2	4				*8*	0	50	50
13				1	1		2	4			*8*	0	50	50
19			1		2	1	1	2	1		*8*	13	63	25
10				1			2	4	1		*8*	13	38	50
2					1				6	1	*8*	88	13	0
12				1				6		1	*8*	13	13	75
9				1	1				4	2	*8*	75	25	0
3				1				4		3	*8*	38	13	50
24				1					4	3	*8*	38	13	50
23				1					3	4	*8*	50	13	38
14				1					4	3	*8*	38	13	50
									Mean			20	38	43

Figure 10.25 UC second Year responses to GeoVAT question 3.

Distribution of responses per question for UC First Year (mean age 20y)

	Time Category (red is a correct response)													
Q	A	B	C	D	E	F	G	H	I	J	*n*	% over estimate	% under estimate	% Correct
4	10	1			1						*12*	17	0	83
11			10				2			1	*13*	30	0	70
18			4	4	2			1			*11*	9	73	18
6		1	5	3	1	1		1			*12*	17	75	8
5				1		8	1	1			*11*	18	9	73
15			1	2	1	3	2	1	1		*11*	18	64	18
16				1		2	6	2			*11*	18	27	55
8				4		2	4	1		1	*12*	17	50	33
20				3	3	1	3		1		*11*	9	64	27
21				1	2	1	3	2	2		*14*	50	29	21
7				1	3	3	4	1			*12*	8	58	33
1					1	4	8		1		*14*	7	36	57
22				1	2	1	3	2	2		*11*	36	36	27
17					1	3	5	1	1		*11*	18	36	45
13							6	3	1	1	*11*	18	55	27
19				2			3	4	1	1	*11*	45	18	36
10				1		1	1	7		2	*12*	17	25	58
2							2	7	1	2	*12*	25	17	58
12							2	4	4	1	*11*	45	18	36
9						1		3	5	3	*12*	67	8	25
3			1					7	2	2	*12*	33	8	58
24									5	7	*12*	58	0	42
23								1	1	9	*11*	81	9	9
14							1		4	8	*13*	62	8	31
									Mean			29	31	40

Figure 10.28. UC Geology student first year responses to GeoVAT question 3.

Fossils and Time: Section B, Question 3 GeoVAT
Distribution of responses per question for UC Postgraduate Geology students (mean age 27y)

	Time Category (red is a correct response)													
Q'n	A	B	C	D	E	F	G	H	I	J	*n*	% over estimate	% under estimate	% Correct
4	**10**										*10*	0	0	100
11			**6**	2	1			1			*10*	40	0	60
18			1	4	**3**	1	1				*10*	20	50	30
6			9	1							*10*	0	100	0
5						**7**	3				*10*	30	0	70
15					1	6	**2**	1			*10*	10	70	20
16							**9**	1			*10*	10	0	90
8					1	3	**6**				*10*	0	40	60
20						3	**5**	1		1	*10*	20	30	50
21						2	**5**	3			*10*	30	20	50
7					1	1	**8**				*10*	0	20	80
1						1	**7**	2			*10*	20	10	70
22					1		**8**	1			*10*	10	10	80
17				1			**9**	1			*10*	10	10	90
13							2	**6**	2		*10*	20	20	60
19						1	1	**8**			*10*	0	20	80
10								**8**	2		*10*	20	0	90
2								**9**	1		*10*	10	0	90
12								**7**	2	1	*10*	30	0	70
9								**3**	3	4	*10*	70	0	30
3									6	4	*10*	100	0	0
24								2	**3**	5	*10*	50	20	30
23								1	**2**	7	*10*	70	10	20
14							1	1	**5**	3	*10*	30	20	50
									Mean			25	19	80

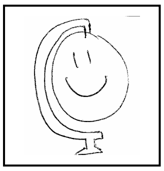
Figure 10.31. Post graduate geology student responses to GeoVAT question 3.

APPENDIX 7

GeoTSAT RESULTS
American University of Beirut (AUB)
Primary Teacher Trainees GeoTSAT Spatialisation

As indicated in Chapter five, achieving a large sample of completed questions is an ideal. It is unfortunate that time and resources do not allow for resending and redoing questionnaires to achieve a higher level of response. Out of a class of 19 primary teacher trainees (mean age of 19 years and 5 months), only 7 responded to the geological structure questions. Questions were either too demanding or completion time was inadequate. Hints that questions 7 and 8 were too difficult as a reason for no response is suggested by an additional 5 responses stating that it was too hard: and therefore they made no response. A typical response to question 8c, where a simple visualisation of a cross section is required is shown below. Was this too hard? Although another response showed concentric layering, it did not have the three rings it had four. It seems again, that **how** students **interpret** questions controls how they answer. The answer below is correct in showing a cross section but does not show the layering: they didn't read the question - or did they?

A typical response to question 8c



Results to Q.6. Mental rotation of letters G and e (n = 10)

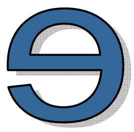
Accepted Responses:

6 a. 1

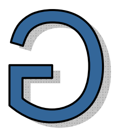
6.a. 2

e and G upside down

6.b.1



6.b.2



e and G right to left rotation

Results:

% correct for 6a. 1 = 60%

% Correct for 6a. 2. = 40%

% Correct for all rotations = 20%

% Correct for 6b. 1. = 80%

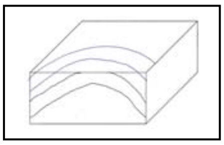
% Correct for 6b. 2. = 20%

It seems that the letter e in this exercise is less difficult to mentally rotate vertically and horizontally than the G and that the most difficult task is mentally rotating the capital G. As mentioned earlier, the ability to mentally rotate can be important for deciphering complexly folded strata and these results hint at the need for further study. For example are all letters equally difficult to rotate, and what about different shapes? The few responses to questions 7 and 8, although frustrating, does provide a glimpse of where these students are at spatial-geologically.

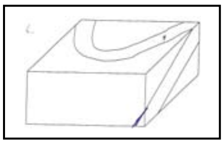
Table 7.3. Summary of AUB (primary) results for questions 7 and 8 (n =7).

Q (AUB p)	Correct	Incorrect
7a	2	5 (71%)
7b	3	4 (57%)
7c	0	5 (100%)
7d	2	3 (60%)
8a (ab + xy)	1	6(86%)
8b	0	0
8c	1	4 (80%)

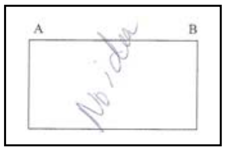
It appears then that in this small sample of 20 year old primary teacher trainees from Lebanon those that were prepared to give a response are not that able in completing the block diagrams, with several indicating that they had no idea. As the complexity of visual spatialisation increased (7c, 7d, 8a and 8b), responses were less confident and generally simple copies of exposed faces were transposed onto other faces of the block. The example response to Q7b was the only example of all cohorts that copied the curved folded strata onto the top surface. It is as if the other surfaces do not exist. Examples are shown below. Clearly, completing the side face was also too difficult for this 21 year old. Q7c posed the greatest difficulties for all cohorts but this example shows how continuing the line onto the front face was a solution (incorrectly). Visually penetrating a 3-D geological structure and drawing the upper curved surface is also too difficult for this 27 year old student (Q7c).



Q 7b



Q7c



Q7d (Cross Section)

There appears then to be little ability to visually penetrate or to follow strata onto a different dimensional perspective for this cohort. This cohort had on average studied some geology when they were about aged 15 but it is highly unlikely that their course involved anything with structural geology and the nature of folded and faulted strata. Having knowledge of this might help, but in general, these results support Devlin's view (2001) that projective (recognition of perspective view change) and Euclidian (use of measurement) spatialisation development happens quite late and requires structured learning experiences.

American University of Beirut (AUB) Secondary Teacher Trainees
GeoTSAT Spatialisation

Results to Q.6. Mental Rotation (n = 14)

e and G upside down

% correct for 6a. 1. = 76%

% Correct for 6a. 2. = 61%

% Correct for all rotations = 40%

e and G back to front

% Correct for 6b. 1. = 66%

% Correct for 6b. 2. = 58%

This cohort of 14 responses from secondary teacher trainees with a mean age of 22 indicates an increase in overall results from their primary teacher trainee colleagues. All respondents of this cohort were university graduates. Explaining the better performance of the younger cohort for Q6b.1 (back to front e), is more difficult. The upside down 'e' seems to be rotated more confidently than that of the back to front e for the secondary trainees than the primary trainees. The lowest score for both groups was the left to right rotation (lateral inversion) of G and there were twice as many 'older' students correct for all rotations.

Table 7.4. Summary of results for AUB (secondary) questions 7 and 8 (n =8).

Q. AUB sec	Correct	Incorrect
7a	5	3 (38%)
7b	2	5 (71%)
7c	1	6 (86%)
7d	0	8 (100%)
8a (ab + xy)	2	6 (86%)
8b	2	6 (86%)
8c	5	3 (38%)

Although marginally better at rotation, this older cohort of teacher trainees seem to be just as inadequate at completing and cross sectioning a geological block diagram as their younger colleagues. The same types of error as (all other groups are displayed where virtually all copied given strata directly onto another face. Another common error was completing only one face suggesting a lack of visual penetrative and 3-D ability. Questions 7d and 8a were beyond this cohort's ability to complete and involve application of VPA. Kali & Orion considered this response to be non-penetrative in the sense that being able to 'see inside from outside' is needed.

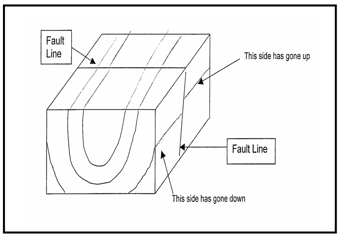
UC (NZ) Secondary Teacher Trainees GeoTSAT Spatialisation

Results to Q.6. Mental Rotation (n = 9)

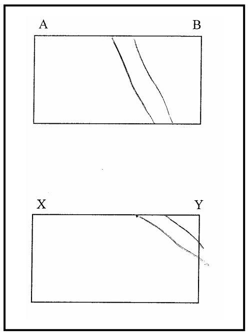
e and G upside down	e and G back to front
% correct for 6a. 1. = 78%	% Correct for 6b. 1. = 100 %
% Correct for 6a. 2. = 78%	% Correct for 6b. 2. = 100%
% Correct for all rotations = 89%	

For this small cohort of twenty seven year old graduates, rotating both letters laterally was not a problem but vertical inversion for both letters was difficult for a few (2/9). The development and teaching interventions for mental rotation about 3 axes deserves further study especially the application of computer assisted rotational spatialisation. Indeed work by Kali (1997; 2002; 2003) has begun this task. Another approach using the ‘hands on’ dry-erase cube (Kuiper, 2008), may also be of great value and one that was employed in an adaptive way, for data gathering discussed in chapter 7 on VPA. Advantages of this approach (with appropriate geological structures) are that it is cheap, does not depend on electronics, is kinaesthetic enables various levels of complexity and available for individuals and small groups. Work by Liben et al. (2009) suggests strongly that more research for example is needed to find the links between the cognitive (projective) development of 3D spatial horizontality and effective pedagogy, especially for students aged 15 to 25. The teaching and learning step that connects the real world (as geology seen in the field) to 2D and 3D mapping, is a further significant challenge and one that could start in the early to mid teens.

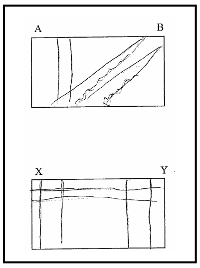
Examples of difficulties experienced by UC secondary respondents are shown below.



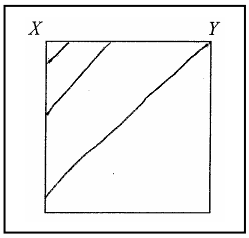
1. Q7d



2. Q8a



3. Q8a



4. Q8b

Kali and Orion (1996) employed Friedman’s two way analysis of variance to test for significant differences in performance on each of the structural problem types (for between 101 and 34 responses for all structural problem types) enabled them to rank the difficulty of the structural problems being tested. The most difficult structural problem was drawing cross sections from complex structures at specific locations such as that in the GeoVAT instrument Section B Q2a, GeoTSAT Q7d and Q8a. The next least difficult were cross sections Q8b and 8c followed by block diagram face completion tasks, Q7a, 7b and 7c.

Question 7d is more complex than questions 7a and 7b because it involves a faulted syncline, (albeit, simply), visual penetration ability as well as completing the surface appearance. A more complex structure would involve a plunging syncline and horizontally (or strike slip) faulted structure. Question 8a involves cross sectioning a plunging anticline but at two different axes. Typical responses shown above indicate the difficulty respondents have with this structural problem. There appears to be little evidence of VPA and difficulty completing the faces. Example 3 shows confusion and indecision while example 2 shows solution by copying the side face onto a cross section. Example 1 illustrates the most common error for question 7d. Where attempted, the strata is simply continued across the fault with little visualisation of the effect the normal fault has of disrupting the strata. If students have not encountered the effects of faulted strata before, it is unlikely to be identified in a complex block diagram. It is also unlikely that this age group are cognitively unable to perform this visualisation (Piaget & Inhelder, 1967), but it demonstrates the power of fieldwork and integrated pedagogies for teaching geological structures and 3D spatialisation (Kail, 1990; Y. Kali, 2002; K. A. Kastens, Ishikawa, T., & Liben, L.S., 2006; J. B. Libarkin, C., 2002; N. Orion, & Hofstein, A., 1991). Model making using isometric 'exploded view' diagrams was always a great way to develop visual-spatialisation skills but they are sill 2-D representations of 3-D. VPA is the ability to 'explode', pull apart and look inside geological structures as well as being able to 'project' to the outside surface. Figure 7.4 shows a typical textbook example of use of a block diagram illustrating a plunging anticline. What is the pattern at the far end like?

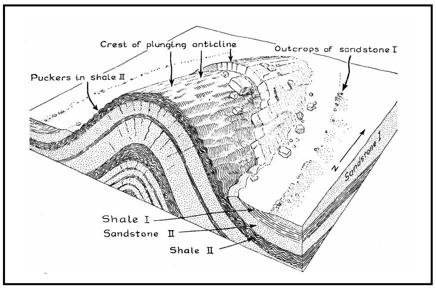


Figure 7.4. A plunging anticline (Gilluly, Waters & Woodford, 1958).

The most common error found for question 8c was the number of layers drawn. Respondents seem to just draw a cross section but fail to read the need for only three layers: a common error across all age groups. Question 8b is a simple tilted strata problem requiring cross sectional VPA through one axis. The most common error, and one that supports Kali and Orion's results, is that of copying given information onto the hidden cross section view. Hidden views require VPA. This group of secondary teacher trainees do not have it. This is likely to reflect the lack of learning experiences in the real world by observing geological exposures, no geological training and minimal cross curricula spatialisation developing experiences. Indeed, finding ways of teaching how to think 3 dimensionally (For teachers and students) from inside the box looking out, and outside the box looking in, is a considerable challenge for curricula and syllabus design. Table 7.5 presents the NZ secondary trainee responses results.

Table 7.5. Summary of Questions7 and 8 for NZ secondary teacher trainees (n =7).

Question	Correct	Incorrect
7a	6	1 (17%)
7b	4	2 (33%)
7c	2	5 (71%)
7d	0	4 (100%)
8a (ab + xy)	3	3 (50%)
8b	3	2 (40%)
8c	6	1 (17%)

AC Year 13 New Zealand Secondary School Responses GeoTSAT

This cohort of final year secondary students (n = 23) had a mean age of 17 years and 9 months. The questionnaire was completed in normal class time in the third of a four term year. All of these students were taking biology with only 10% taking two sciences and 5% taking three sciences. Most of this cohort would enter a university the following year.

Results to Q.6. AC Year 13 Mental rotation responses (n = 23)

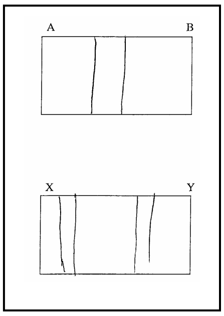
e and G upside down	e and G back to front
% correct for 6a. 1. = 78%	% Correct for 6b. 1. = 100%
% Correct for 6a. 2. = 83%	% Correct for 6b. 2. = 100%
% Correct for all rotations = 80%	

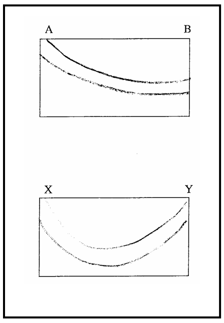
Mental rotation appears not to be a major difficulty for this small cohort but oddly, vertical rotation for both letters was more difficult than the lateral inversion. The most common problem for incorrect answers was confusion of left to right when the letters are inverted. This age group can mentally rotate.

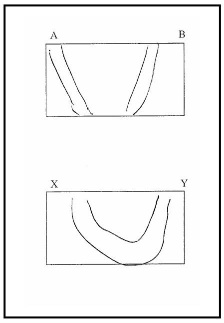
Table 7.6. Summary of results for AC Year thirteen (n = 17 to 24).

Question	No. Correct	No. Incorrect
7a	21	3 (13%)
7b	10	13 (56%)
7c	3	20 (87%)
7d	7	16 (70%)
8a (ab)	0	20 (100%)
8a (xy)	0	20 (100%)
8b	9	8 (47%)
8c	18	3 (14%)

Results for this age group (Table 6.6) follow a similar pattern to others: as complexity increases and the need for VPA increases such as for fold structure solutions, fewer responses are correct. Projecting strata onto two faces is difficult (Q7d), and drawing the ‘exploded’ VPA faces with correct strata positions (Q8a) for two cross sections is too difficult. 3-D Euclidean geometry ability seems to be poorly developed. How has mathematics curricula changed for teaching and learning geometry? The following examples show typical responses for Q8a: cross section VPA on a plunging anticline.







(a) Most common (b) 'Face' copying (c) 'Face' copying

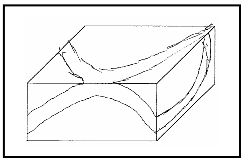
No response to Q8a had the strata bedding plane correct. Strata were only translated vertically downward rather than diagonally despite a partial answer being displayed in Q.7.d (See (a) above). This suggests that these students were unable to visually penetrate to the hidden strata dipping downwards and connecting with the front face of the block. Diagrams (b) and (c) above suggest the common copying of the top surface to the side face and the front face, which are of course parallel to a-b and x-y. It seems difficult for students to be able to connect the 'inside' cross section a-b and x-y with that of these parallel faces. In other words, they do not see the strata patterns on the edge faces of the block as being the same as the cut away cross sections. Questions 8b and c also follow common errors: diagonal strata copying of one face for 8b and not putting the correct number of layers for Earth's interior cross section. Copying one face as a cross section suggests that this cohort is generally unable to visually penetrate the cross section. In fact there is a tendency to just draw diagonal lines (47% of responses) with an apparent ignorance of how X-Y cuts vertically down through the strata. Although the correct position of strata bedding planes is rarely seen, this was disregarded in favour of a correct pattern. However, translating plan view into cross sectional view as in geological cross sections requires relative positions of strata to be accurate. Geological cross sections are important to enable visualisation of surface topography and geology and relationships of strata at depth. Seeing inside and the hidden view is what structural geology is all about: it is another piece to the jigsaw earth history. None of this cohort has experienced geological block diagrams before.

AC Year 11 New Zealand Secondary School Responses GeoTSAT

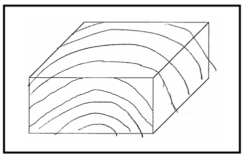
Responses for this younger group of students (mean age of 15 years and 8 months and the age group tested by the OECD PISA programme), indicates less difficulty with rotation where only one of all responses was incorrect (n = 13). There appears to be greater difficulty with cross sectioning and block diagram completion of structures although the Earth's interior cross section was less difficult. This is shown by not only the greater variety of incorrect responses but also the higher number of incorrect and random guessing type answers. The following table summarises the results for questions 7 and 8 (n = 13):

Dominant responses for all structure completion tasks were again, copies of strata patterns onto the block faces (including cross sections). Some examples are shown below. There is also a tendency to just complete the patterns with no regard to its expression on another block face. VPA is not yet developed. And moving from the familiar to the unfamiliar is still formative.

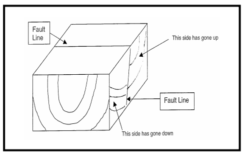
(a)



(b)



(c)



Responses (a) and (b) illustrate a common incorrect answer, where given strata is copied as if the single face given has to be repeated on all other faces. Diagram (c) indicates recognition that there has been displacement (because the information says so) but this response also does not indicate how the strata are disrupted on the top surface. This requires VPA.

Table 7.7 . Summary of results for AC Year 11.

Question	No. Correct	No. Incorrect
7a	3	19 (86%)
7b	7	14 (67%)
7c	3	19 (86%)
7d	5	16 (76%)
8a (ab)	3	15 (83%)
8a (xy)	0	17 (100%)
8b	12	4 (25%)
8c	13	3 (19%)

UC First Year Responses to GeoTSAT

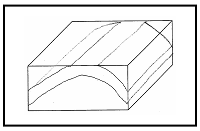
Another small cohort of 16 to 24 responses, these students are all first year geology students at a university and a year in advance of year 13, NZ secondary school students. In general, errors are the same as all other cohorts. They have a mean age of 20 years and 6 months but with the oldest student at 63 years old!

Only one response was incorrect for mental rotation of both letters, and that was the 63 year old male.

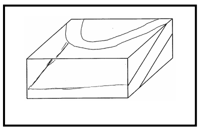
Table 7.8. Summary of results for UC first year students.

Question	No. Correct	No. Incorrect
7a	11	2 (15%)
7b	5	8 (62%)
7c	1	12 (92%)
7d	2	11 (85%)
8a (ab)	6	7 (54%)
8a (xy)	5	8 (62%)
8b	6	6 (50%)
8c	9	3 (25%)

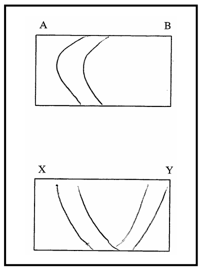
An unusual aspect of this group was that several students tried to draw 3-D structures **within** the block e.g. Q7a and Q7b below: no other group tried to do this. Some examples of this are shown below. Perhaps they were flexing a new found spatial skill or perhaps it was a genuine way of 'solving the problem'?



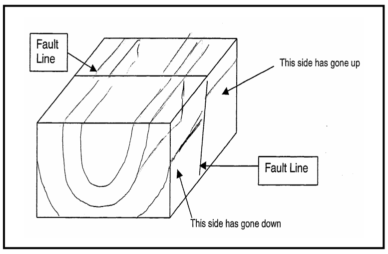
Q7b



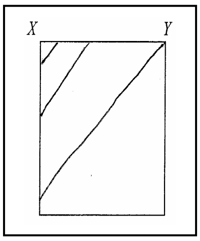
Q7c



Q8a



Q7d



Q8b

With novice training in geology perhaps this group saw the boxes as the boundaries to be drawn in rather than the edges of the block to be drawn on. Q7c reveals how this respondent has attempted to complete the side face but has not been able to reconcile the top with the end face. These examples show a measure of visual penetration with completion of only one side and no penetration with the folded top surface, thus ending up in a kind of 'Esheresque' muddle. Completion of cross sections *a-b* and *x-y* for question 8 caused the same kind of visualisation difficulties as all other groups. VPA is still in a developmental phase.

The example response to Q7d indicates an ability to recognise the continuation of strata bedding of the front edge and side surface (with correct relative movement), but an inability to perceive how a vertical movement along the fault would impact on the top surface pattern of the syncline. There appears to be difficulty moving from side surface that has moved vertically to the top surface which is drawn as a lateral offset rather than a vertical offset where the syncline would appear to move inwards (see accepted model answer). This example also attempted to draw a 3D picture inside the block diagram. Drawing a cross section for inclined strata posed less difficulty but with the same incorrect 'face' copying solution as all other groups as shown in the example. Drawing a cross section of a sphere with 3 layers was not a major problem for 79% of the responses.

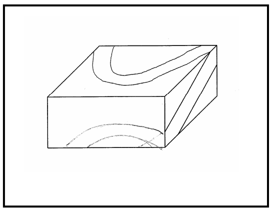
UC Second Year Responses to GeoTSAT

The mean age for this cohort of 9 respondents was 22 years and 6 months. Not all respondents answer all questions. All respondents were committed geology students in their second year at a university. Only one student was incorrect for mental rotation of both letters, and this was for the vertical rotation and not lateral rotation. Mental rotation continues to be the least difficult visual spatialisation skill and in line with other cohorts. Results to questions 7 and 8 are summarised below.

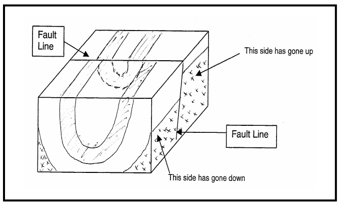
Table 7.9. Summary of results for UC second year students.

Question	No. Correct	No. Incorrect
7a	9	0 (0%)
7b	7	2 (22%)
7c	4	5 (56%)
7d	6	3 (33%)
8a (ab)	8	1 (11%)
8a (xy)	6	3 (33%)
8b	9	0 (0%)
8c	9	0 (0%)

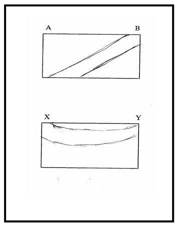
VPA appears less a problem and better developed for this cohort, but incorrect responses are the same as all other cohorts: incomplete block faces, 'face' copying and lack of VPA, especially (surprisingly) for question 7d which typically returned a straight bedding plane rather than curved (See below). One response was "internal' 3D in the same way that many were at UC Level 2 (See below). Perhaps this illustrates how respondents attempt to visually penetrate the block; by physically drawing in the envisioned continuation of strata? Spatially visualising folded strata is a difficult task even for 23 year old university geology students



Q7c



Q7d



Q8a

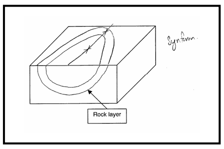
Q7c example above is a good example of indecision. IT seems that this respondent has started off with a ‘straight’ continuation of strata ‘around the corner’ but then realised that it is folded upward but still not quite correct. Q7d above indicates a typical 3-D attempt to draw in the VPA rather than just completing the top surface. This example gives a clue as to how the solution is derived, where a VPA is actually drawn in but en not ignored. Q8a is a typical response: the *ab* strata section is in the correct direction but not in the correct position. Translating plan view to cross section with all parts in the correct relative position appears to be of secondary importance to getting the direction right. Section *x-y* for Q8a indicates a mirror copy of the top surface. These results are typical of the VPA errors found in Kali and Orion’s work of 1996.

Remembering that these responses are from 23 year old university geology students, slicing a sphere in half and drawing the concentric layering inside (Q8c) provided little difficulty. Spatial familiarity in a geological context is an important notion: students need to be exposed to a variety of learning experiences in order to develop better visualisation in seeing ‘inside’ and hidden patterns. There is much room for cross curricular pedagogy in visual spatial learning.

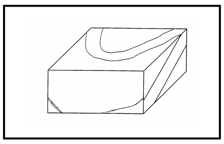
UC Post Graduate Responses to GeoTSAT

The mean age for this post graduate geology cohort (n =10) was 26 years and 6 months. These students were studying geology at the PhD, MSc and BSc(Hons) levels, so a high level of correct responses was expected.

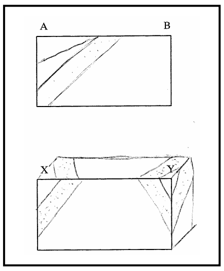
All responses were correct for mental rotation of letters both for vertical and lateral inversion. Mental rotation is not a problem for this age group. However, although the percentage of incorrect responses for questions 7 and 8 were significantly lower (See summary) than all other cohorts, there were still some responses indicating the same kind of errors exhibited by all other cohorts: non penetrative VPA, incomplete sections, copying 'faces' and 'mirror imaging' of strata such as in AC year 11 (a). Kali and Orion (1996) indicated non penetrative responses to include: complete and partial copying of faces, unfolding of two faces, 2 dimensional cross sectioning and combining portions of each block diagram face. Drawing or attempting to draw a cross section and drawing an 'internal' continuation of strata from one face (usually the top) onto another 'face' were considered by Kali & Orion to be penetrative responses. The diagram below shows examples of postgraduate responses.



1. Q7a

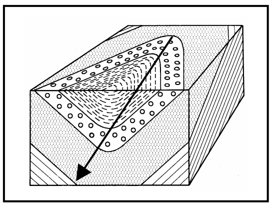


2. Q7c



3. Q8a

Example 1 above was the only response from all cohorts that showed an interpretation of the horizontal syncline as plunging or pitching. It was labelled as a synform. This MSc student simply drew a preconceived pattern rather than looking at the given diagram. If it was plunging then the end pattern would be as below.



Plunging syncline (Figure 7.5) showing the end pattern further splayed apart than that of a 'horizontal' syncline. As the angle of pitch increases, the 'limbs' move apart from an end view

Figure 7.5. Plunging syncline block diagram.

VPA skill involves perceiving how the cross section (not the longitudinal section) changes as the angle of pitch changes. As well as perceiving the effect of where the planar sections are. Response 2 for Q7c is a typical 'mirror image' copy of the top surface and indicates that this respondent had no VPA for this structure. The end completion pattern simply mirrors the top surface and does not connect with the side face other than continuing the top bedding ‘around the corner’. This student was also an MSc student. Example 3 for Q8a indicates a penetrative ability by attempting to draw a continued 3-D drawing of the front end pattern; an unusual approach but one that reveals the kind of 3d thinking going on. Table 6.10 summarises the results for questions 7 and 8 of the GeoTSAT instrument. As can be seen, VPA and general visual spatialisation has been further developed in this cohort as a result of three plus years of postgraduate experiences in geology. Nonetheless, errors that are made are similar to all other age groups.

Table .7.10. Summary of results for UC Postgraduate students.

Q	No. Correct	No. Incorrect
7a	9	1 (10%)
7b	9	1 (10%)
7c	8	2 (20%)
7d	8	2 (20%)
8a (ab)	8	2 (20%)
8a (xy)	7	3 (30%)
8b	10	0 (0%)
8c	10	0 (0%)

Israeli (IS) Secondary Students Responses to GeoTSAT: Grades 8, 10 and 12.

This cohort consists of three age groups from a secondary school (Grades 8, 10 and 12). Response rates range from 5 to 23 as a result of question selection by the respondent as well as inability to complete. Failure to respondent due to inability is not measurable, but sometimes respondents show accurate response for some questions but just leave the others out. Collectively there were 59 respondents. This Israeli cohort collectively displayed the greatest variety of response to the GeoTSAT.

Results

Hebrew is a completely different written and spoken language to English and is a barrier for gathering information. Response results are shown in table 6.11. For question one, the English letters **e** and **G** may have meant very little too many respondents and so they ignored the question? The relationships between language, hearing, writing and spatialisation are an area of fertile future research. Q6a, the vertical rotation of letters e and G, was poorly answered by most respondents but overall, mental rotation (like all other cohorts), is not a major difficulty for these students aged 13 to 18. However, lateral rotation appeared to be much easier than vertical rotation.

Table 7.11. Summary of Israeli percentages of incorrect answers for each age group for the GeoTSAT geological structures.

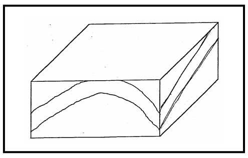
	% of Incorrect Responses			
Question	IS Grade 8	IS Grade 10	IS Grade 12	All
7a	1/21 = 5%	0/15 = 0%	2/23 = 9%	5%
7b	14/19 = 74%	5/15 = 33%	15/23 = 65%	59%
7c	14/14 = 100%	14/14 = 100%	24/24 = 100%	100%
7d	9/9 = 100%	13/14 = 93%	17/19 = 89%	92%
8a (ab)	5/6 = 83%	13/15 = 87%	23/23 = 100%	93%
8a (xy)	5/5 = 100%	15/15 = 100%	22/22 =100%	100%
8b	5/6 = 83%	2/12 = 17%	10/20 = 50%	45%
8c	3/5 = 60%	3/11 = 27%	6/18 = 33%	36%

Q7a provided the least difficulty for all age groups. This may be due to the fact that only the top surface is required to be completed. It is a different matter when two faces are required to be connected, as this needs a degree of VPA and 'projection' or completion ability as in Q7b. This question was better perceived than all other geological structures. Although Q7c requires only the end pattern to be completed it is complicated with the need for a higher degree of VPA. This is generated by the folded nature of the strata. Only one response from 44 was correct and mirrors the overall difficulty of this structure. Question 7d not only requires completion of two surfaces, but has the added VPA difficulty of visualising the effect of vertical movement of a fault on a horizontal fold for top and side surfaces of the block diagram. This difficulty is common to all cohorts. A combination of error types were displayed suggesting underdeveloped spatial reasoning and VPA. Q8a cross sections again exposed the difficulty of rotating and 'exploding' the plunging anticline.

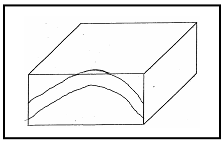
Again, few respondents recognise the given side surface as part of the solution! If you can't visually penetrate, then it will mean nothing. Question 8b revealed a better correct answer rate from all age groups and also a large variety of solution. This is likely due to the simpler nature of inclined planes. However, errors were in common with all other cohorts mostly related to the inability to slice open and split to real the inside face. It is the position of the cross section that appears to cause difficulties. Many incorrect answers copy the front face but do not take identify that the cross section XY does not precisely correspond to the front face. Other incorrect responses are the same as that recorded by Kali and Orion particularly direct copying of the front face occurs. Visual penetrative responses require the ability to split open the block along the cross sectional line and visualise the strata pattern translated from the given faces.

Selected examples of incorrect responses for Israeli secondary students.

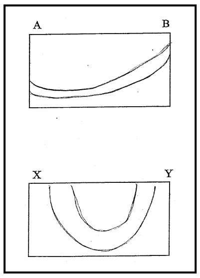
1. IS Grade 8



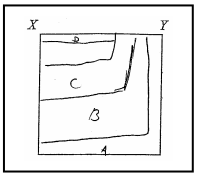
Q7b



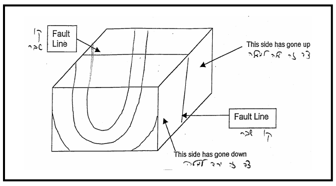
Q7b



Q8a

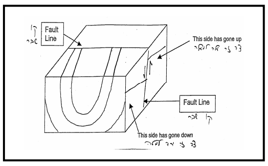


Q8b

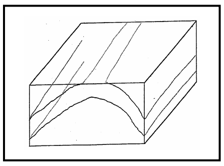


7d

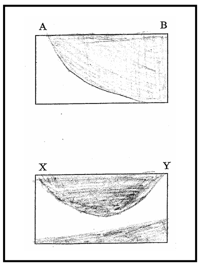
2. IS Grade 10



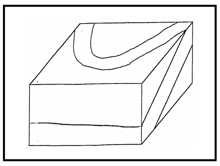
Q7d



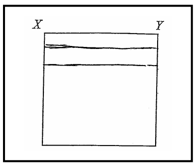
Q7b



Q8a

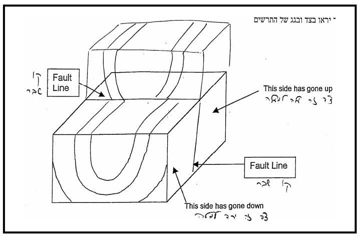


Q7c

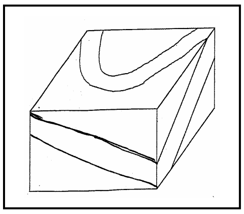


Q8b

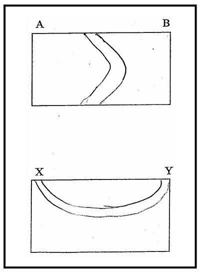
3. IS Grade 12



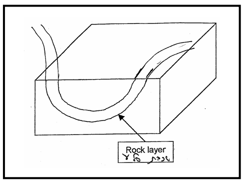
Q7a



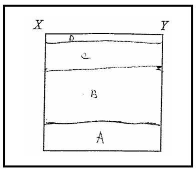
Q7b



Q8a



Q7d



Q8b

The scanned illustrations of the IS secondary school cohort display a range of VPA errors and 3-D visualisations across an age range of 13 to 17 years. Across all age groups there are responses that range from a clear indication of 3-D VP ability to partial VPA to no VPA and to simple copying of surface patterns onto any face. Simple copying is often only on one face, suggesting a spatial disconnection between block faces and therefore an undeveloped VPA and general spatialisation skills.

Along with question 7d of IS grade 8, question 7b also illustrates this disconnection of block diagram surfaces. Indeed, Q7d of this group shows how this respondent continues the fold limb in cross section straight across the top surface with no connection with the side face and the effect of fault disruption. Is this just a recognitional copy of question 7a? Cross section 8a illustrates a typical response across all age groups from all cohorts for this puzzle: inability to split open and visually penetrate the exposed surface downwards results in copying the fold onto a surface. The cross section illustrated for Q8b was unusual but is an example of what Kali and Orion (1996) described as an incorrect penetrative response. Bending the layers appears to be an attempt to place the strata from two faces onto one, or trying to combine by unfolding the two exposed surfaces onto a single block face. Visualising the 3-D connections is a difficult task for this grade 8 age group.

Israeli grade 10 responses also show a developing VPA. The response to Q7d for example indicates recognition of connected faces but then got stumped by the effect of the fault movement on the strata exposed on the top surface. This also stumped many students studying geology at higher levels. The side face correctly showed the relative movement of strata but this was unable to be translated onto the top surface. Q7b response was included to illustrate a correct response but one that attempts to draw the 3D shape within the block much like that of UC Year 1 responses. The example response to Q7c is typical in showing how the folded nature of the strata is not visualised in cross section with any penetration. The side pattern is in all cases simply ’continued round the corner’. The cross section illustrated for Q8a is unusual in that a ‘negative’ picture is drawn in which the ‚curves’ of the folded strata are simply copied onto the surfaces. No VPA is exhibited here. Q8b shows the ability to visually penetrate but not with accuracy so this would be partially correct.

Grade 12 responses also show a range of error types. The response to Q7d is very unusual in that the fold is simply continued with no connection to the block diagram. There is certainly no connection of top and side surfaces of the block diagram. The response shown for Q7b also shows the difficulty of visually penetrating the block where there are folded strata. Only one side is continued and is disconnected from the top surface. This response was unusual in that the strata is continued up an angle rather than going straight across: a copy of the side face onto the end face. The cross sections illustrated show typical responses where VPA occurs, but not where the section line cuts the block. Q8a is a copy of curved surfaces nto an unimagined split open surface. No VPA here. Q7a response is interesting as in indicates how this student is starting to think with VPA. There is recognition of the fault movement on the side face (although not completed) and its effect on the fold structure pattern on the top surface. This is unusually drawn as a block being moved upward but not planed off and the pattern drawn on the flat top surface. This kind of approach was only seen in the UC second year cohort. It is a copy of the front surface correctly put in position but not understood in terms of resultant strata pattern. As Kali and Orion (1996) found, and this study supports, copying of one of the faces was the dominant error for attempted VPA responses. This reflects an underdeveloped spatial sense and lack of visual penetrative experiences.

Table 7.12. Percentage of **incorrect** answers to GeoTSAT spatialisation questions per cohort (See Appendix 8 for t-Test statistical analysis).

	Percentage of Incorrect Responses to GeoTSAT Spatialisation Questions							
Cohort	7a	7b	7c	7d	8a(i)	8a(ii)	8b	8c
AUB Prim. Teacher Trainees	38	71	86	100	86	86	86	38
AUB Sec. Teacher Trainees	71	57	100	60	86	86	0	80
UC Sec. Teacher Trainees	17	33	71	100	50	50	40	17
AC Year 13	13	56	87	70	100	100	47	14
AC Year 11	15	62	92	85	54	62	50	25
UC 1st Year Geology students	86	67	86	76	83	100	25	19
UC 2nd Year Geology students	0	22	56	33	11	33	0	0
UC Geology Post Graduates	10	10	20	20	20	30	0	0
IS Grade 8	5	74	100	100	83	100	83	60
IS Grade 10	0	33	100	93	87	100	17	27
IS Grade 12	9	65	100	89	100	100	50	33

APPENDIX 8

Statistical Data for Chapter 7: GeoTSAT Reliability

Student ID #	Cohort	Q 7a	Q 7b	Q 7c	Q 7d	Q 8a (i)	Q 8a (ii)	Q 8b	Q 8c
	See Key below	'1' = correct responses, '0' = incorrect responses							
1	1	1	1	0	1	0	0		0
2	1	1	1	0	1	0	0		0
3	1	0	1	0	0	0	0		0
4	1	0	0	0	0	0	0		0
5	1	0	0	0	0	0	0		1
6	1	0	0			0	0		
7	1	0	0			1	1		
8	2	1	1	1	0	0	0	0	1
9	2	1	1	0	0	0	0	0	1
10	2	1	0	0	0	0	0	0	1
11	2	1	0	0	0	0	0	0	0
12	2	1	0	0	0	0	0	0	0
13	2	0	0	0	0	1	1	0	0
14	2	0	0	0	0	1	1	1	0
15	2	0			0			1	0
16	3	1	1	1	0	1	1	1	1
17	3	1	1	1	0	1	1	1	1
18	3	1	1	1	0	1	1	1	1
19	3	1	1	1	0	0	0	0	1
20	3	1	0	1	1	0	0	0	1
21	3	1	0	0		0	0		1
22	3	0		0					0
23	4	1	1	1	1	0	0	1	1
24	4	1	1	1	1	0	0	1	1
25	4	1	1	1	1	0	0	1	1
26	4	1	1	0	1	0	0	1	1
27	4	1	1	0	1	0	0	1	1
28	4	1	1	0	1	0	0	1	1
29	4	1	1	0	1	0	0	1	1
30	4	1	1	0	0	0	0	1	1
31	4	1	1	0	0	0	0	1	1
32	4	1	1	0	0	0	0	0	1
33	4	1	0	0	0	0	0	0	1
34	4	1	0	0	0	0	0	0	1
35	4	1	0	0	0	0	0	0	1
36	4	1	0	0	0	0	0	0	1
37	4	1	0	0	0	0	0	0	1
38	4	1	0	0	0	0	0	0	1
39	4	1	0	0	0	0	0	0	1
40	4	1	0	0	0	0	0	0	1
41	4	1	0	0	0	0	0		0
42	4	1	0	0	0	0	0		0
43	4	1	0	0	0				0
44	4	0	0	0	0				
45	4	0	0	0	0				
46	4	0	0	0					

47	5	1	1	1	1	1	1	1	1
48	5	1	1	0	1	1	1	1	1
49	5	1	1	0	0	1	1	1	1
50	5	1	1	0	0	1	1	1	1
51	5	1	1	0	0	1	1	1	1
52	5	1	0	0	0	1	0	1	1
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54	5	1	0	0	0	0	0	0	1
55	5	1	0	0	0	0	0	0	1
56	5	1	0	0	0	0	0	0	0
57	5	1	0	0	0	0	0	0	0
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59	5	0	0	0	0	0	0		
60	6	1	1	1	1	1	0	1	1
61	6	1	1	1	1	1	0	1	1
62	6	1	1	1	1	1	0	1	1
63	6	0	1	0	1	0	0	1	1
64	6	0	1	0	1	0	0	1	1
65	6	0	1	0	0	0	0	1	1
66	6	0	1	0	0	0	0	1	1
67	6	0	0	0	0	0	0	1	1
68	6	0	0	0	0	0	0	1	1
69	6	0	0	0	0	0	0	1	1
70	6	0	0	0	0	0	0	1	1
72	6	0	0	0	0	0	0	1	1
73	6	0	0	0	0	0	0	0	1
74	6	0	0	0	0	0	0	0	0
75	6	0	0	0	0	0	0	0	0
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77	6	0	0	0	0	0	0		
78	6	0	0	0	0	0			
79	6	0	0	0	0				
80	6	0	0	0	0				
81	6	0	0	0	0				
82	6	0		0					
83	7	1	1	1	1	1	1	1	1
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102	9	1	1	0	0	0	0	0	0

103	9	1	1	0	0	0	0	0	0
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105	9	1	1	0	0	0	0	0	1
106	9	1	1	0	0	0	0	0	1
107	9	1	0	0	0	1		1	
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109	9	1	0	0	0				
110	9	1	0	0	0				
111	9	1	0	0					
112	9	1	0	0					
113	9	1	0	0					
114	9	1	0	0					
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117	9	1	0						
118	9	1	0						
119	9	1	0						
120	9	1	0						
121	9	1	0						
123	9	0	0						
124	10	1	0	0	0	0	0	0	0
125	10	1	0	0	0	0	0	0	0
126	10	1	0	0	0	0	0	1	0
127	10	1	0	0	0	0	0	1	1
128	10	1	0	0	0	0	0	1	1
129	10	1	1	0	0	0	0	1	1
130	10	1	1	0	0	0	0	1	1
131	10	1	1	0	0	0	0	1	1
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133	10	1	1	0	0	0	0	1	1
134	10	1	1	0	0	0	0	1	1
135	10	1	1	0	0	0	0	1	
136	10	1	1	0	0	0	0		
137	10	1	1	0	0	1	0		
138	10	1	1		1	1	0		
139	11	0	0	0	0	0	0	0	0
140	11	0	0	0	0	0	0	0	0
141	11	1	0	0	0	0	0	0	0
142	11	1	0	0	0	0	0	0	0
143	11	1	0	0	0	0	0	0	0
144	11	1	0	0	0	0	0	0	0
145	11	1	0	0	0	0	0	0	1
146	11	1	0	0	0	0	0	0	1
147	11	1	0	0	0	0	0	0	1
148	11	1	0	0	0	0	0	0	1
149	11	1	0	0	0	0	0	0	1
150	11	1	0	0	0	0	0	1	1
151	11	1	0	0	0	0	0	1	1
152	11	1	0	0	0	0	0	1	1
153	11	1	0	0	0	0	0	1	1
154	11	1	0	0	0	0	0	1	1
155	11	1	1	0	0	0	0	1	1
156	11	1	1	0	1	0	0	1	1
157	11	1	1	0	1	0	0	1	
158	11	1	1	0		0	0	1	

159	11	1	1	0		0	0	1	
160	11	1	1	0		0	0		
161	11	1	1	0		0			
162	11			0					

Cohort Codes

1 AUB primary school teacher trainees
2 AUB secondary school teacher trainees
3 NZ secondary school trainees
4 AC Year 13
5 AC Year 11
6 UC First Year Geology students
7 UC Second Year Geology students
8 UC Postgraduate Geology students
9 IS Grade 8
10 IS Grade 10
11 IS Grade 12

Cronbach's Internal Consistency Results (Peladeau & Lacouture, 1993)

Mean inter-item correlation = 0.4447 (0.45)
Cronbach's alpha = 0.8488 (0.85)
Standardised item alpha = 0.8486 (0.85)
111 valid cases and 63 invalid cases

Note that total number of responses used for questions 1 and question 3 have had invalid responses removed. This explains why reliability data used is slightly different to that of other results.

SPSS Analysis
Scale: ALL VARIABLES

Case processing summary

		N	%
Cases	Valid	111	100.0
	Excluded[a]	0	0.0
	Total	111	100.0

a. Listwise deletion based on all variables in the procedure

Reliability Statistics

Cronbach's alpha	N of items
0.849	7

Item-Total Statistics

	Scale mean if question deleted	Scale variance if question deleted	Corrected question – Total correlation	Cronbach's Alpha if question deleted
Question 7b	2.37	3.653	0.634	0.824
Question 7c	2.66	3.882	0.644	0.823
Question 7d	2.61	3.767	0.668	0.819
Question 8a(i)	2.61	3.730	0.692	0.815
Item 8a(ii)	2.68	3.948	0.623	0.826
Question 8b	2.29	3.734	0.601	0.830
Question 8c	2.08	4.293	0.403	0.855

GeoVAT Question 1 : Ideas about Fossils Reliability Data

Student ID #	Cohort	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18
										‘1’ = correct, ‘0’ = incorrect									
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
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10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
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14	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1
15	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1
16	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	0	1	1
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19	1	1	1	1	1	1	1	1	1	0	0	0	1	0	1	0	0	1	0
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23	1	1	1	1	0	1	1	1	1	0	0	0	0	0	0	0	0	1	0
24	1	1	1	1	0	1	1	1	1	0	0	0	0	0	0	0	0	1	0
25	1	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	1	0

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27	1	1	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0
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29	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
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31	2	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0
32	2	1	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	0
33	2	1	1	1	1	1	1	0	1	1	0	1	1	1	1	1	0	1	0
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37	2	1	1	1	1	1	0	0	1	1	0	0	0	0	1	0	0	0	0
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166	9	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0
167	9	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
168	9	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
169	9	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
170	10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
171	10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
172	10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	0
173	10	1	1	1	1	1	1	1	1	1	0	1	1	0	1	0	0	1	0
174	10	1	1	1	1	1	1	1	1	0	0	0	1	0	1	0	0	1	0
175	10	1	1	1	0	0	0	1	1	0	0	0	1	0	1	0	0	1	0
176	10	1	1	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
177	11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
178	11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
179	11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
180	11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
181	11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
182	11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
183	11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0
184	11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0
185	11	1	1	1	1	1	1	1	1	1	0	1	1	0	1	0	1	0	0
186	11	1	1	1	1	1	1	1	1	1	0	1	1	0	1	0	0	0	0
187	11	1	1	1	1	1	1	1	1	1	0	1	1	0	1	0	0	0	0
188	11	1	1	1	1	1	1	1	1	0	0	1	0	0	1	0	0	0	0
189	11	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
190	11	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0
191	11	1	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
192	12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

193	12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
194	12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
195	12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
196	12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
197	12	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	0	1	1
198	12	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	0	1	1
199	12	1	1	1	1	1	1	1	1	0	1	1	1	0	1	0	0	1	1
200	12	1	1	1	1	1	1	1	1	0	0	1	1	0	1	0	0	1	1
201	12	1	1	1	1	1	1	1	1	0	0	1	1	0	1	0	0	1	1
202	12	1	1	1	1	1	1	1	1	0	0	0	1	0	1	0	0	1	1
203	12	1	1	1	1	1	1	1	1	0	0	0	1	0	1	0	0	1	1
204	12	1	1	1	1	1	1	1	1	0	0	0	1	0	1	0	0	1	1
205	12	1	1	1	1	1	1	1	1	0	0	0	1	0	1	0	0	1	1
206	12	1	1	1	0	1	0	1	0	0	0	0	1	0	1	0	0	1	1
207	12	1	1	1	0	1	0	1	0	0	0	0	1	0	1	0	0	1	1
208	12	1	1	1	0	0	0	1	0	0	0	0	1	0	1	0	0	1	1
209	12	1	1	1	0	0	0	1	0	0	0	0	1	0	1	0	0	1	0
210	12	1	1	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0

1 = UCL1
2 = UC L2
3 = UC PG
4 = IS Y12
5 = IS Y13
6 = AC Y13
7 = AC 12
8 = AC Y11
9 = AC Y 9
10 = AUB Sec
11 =UC Sec
12 = AUB Prim

Reliability Statistics of Q1, Section A, GeoVAT

Mean inter-item correlation = 0.4220 (0.42)
Cronbach's Alpha = 0.9292 (0.93)
Standardised item Alpha = 0.9293 (0.93)
208 cases and 13 invalid

CeoVAT Reliability for Question 3: Fossils and Time.

Student ID #	Cohort	Q 1	Q 2	Q 3	Q 4	Q 5	Q 6	Q 7	Q 8	Q 9	Q 10	Q 11	Q 12	Q 13	Q 14	Q 15	Q 16	Q 17	Q 18	Q 19	Q 20	Q 21	Q 22	Q 23	Q 24
		1 = correct 0 = incorrect																							
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	0	1	0	1
4	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0	0	1	1	0	1	0	0	0	0	1
5	1	1	1	1	1	1	1	0	0	0	1	1	0	0	0	0	1	1	0	0	0	0	0	0	0
6	1	1	1	1	1	1	0	0	0	0	1	1	0	0	0	0	1	1	0	0	0	0	0	0	0
7	1	1	1	1	1	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
8	1	1	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
9	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
10	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
11	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0			0	0			0			0
13	1	0							0				0		0			0	0			0			
14	1	0																				0			
15	2	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1
16	2	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1	1	0	0	1	1	1
17	2	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	0	0	0	0	1	1	1
18	2	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	0	0	0	0	0	0	1
19	2	0	1	0	1	1	1	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0
20	2	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
21	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

22	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
24	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
25	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1
26	3	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	0	1	1	1	1	0	0
27	3	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	0	1	1	1	1	0	0
28	3	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	1	1	0	1	0	0	1	0	0
29	3	1	1	0	1	1	1	1	0	0	1	0	1	0	0	0	1	1	0	1	0	0	1	0	0
30	3	0	1	0	1	0	1	1	0	0	1	0	0	0	0	0	1	1	0	1	0	0	1	0	0
31	3	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
32	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	4	1	1	0	1	1	1	1	1	0	0	1	0	0	0	0	1	0	0	0	1	1	0	0	0
34	4	0	1	0	1	1	1	1	1	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0
35	4	0	1	0	1	1	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
36	4	0	1	0	0	0	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
37	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	5	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1
44	5	1	1	1	1	1	0	0	1	1	0	1	1	1	1	0	1	0	1	0	0	0	1	0	0
45	5	0	0	1	1	0	0	0	1	0	0	0	1	0	0	0	1	0	1	0	0	0	1	0	0
46	5	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0
47	5	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

50	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53	6	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
54	6	1	0	0	0	1	1	1	1	0	0	1	0	1	0	0	0	0	0	1	0	1	0	1	1
55	6	0	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	1	1
56	6	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1
57	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
58	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
59	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65	7	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1
66	7	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	0	0	1	0	1
67	7	1	1	1	1	1	1	1	1	0	1	0	1	1	1	0	0	1	1	0	0	0	1	0	1
68	7	1	1	1	1	1	0	0	1	0	1	0	1	1	1	0	0	1	0	0	0	0	0	0	1
69	7	1	1	0	1	1	0	0	1	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0
70	7	0	0	0	1	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
71	7	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
72	7	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
73	7	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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75	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
77	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

78	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
79	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
81	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
82	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
83	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	8	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
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88	8	0	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
89	8	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
90	8	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
91	8	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
92	8	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
93	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
95	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
97	8	0	0		0	0			0				0		0	0	0		0	0		0			0
98	8		0		0								0		0	0						0			
99	8				0																	0			
100	9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	0	0	0
101	9	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	0	0	1	0	1	0	0	0
102	9	0	1	1	1	1	0	1	0	0	0	0	0	0	1	1	1	0	0	1	0	0	0	0	0
103	9	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
104	9	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
105	9	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

106	9	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
107	9	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
108	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
109	10	1	1	1	0	1	0	0	1	1	1	0	1	1	1	0	1	0	1	0	0	0	0	1	0
110	10	1	1	1	0	1	0	0	1	0	1	0	1	1	1	0	1	0	1	0	0	0	0	0	0
111	10	1	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0
112	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
113	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
114	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
115	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
116	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
117	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
118	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
119	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
120	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
121	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
122	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Cohort Key

1 = UCL1

2 = UC L2

3 = UC PG

4 = IS Y12

5 = IS Y13

6 = AC Y13

7 = AC 12

8 = AC Y11

9 = UC Sec

10 = AUB Prim

GeoVAT Data Reliability Statistics for Q3, Section B GeoVAT

Cronbach's Internal Consistency Results (Peladeau & Lacouture, 1993).

Mean inter item-correlation = 0.5493 (0.55)
Cronbach's alpha = 0.9673 (0.97)
Standardised item alpha = 0.9689 (0.97)
115 valid cases and 18 invalid cases.

ANOVA (Excel) for Table 6.12, Appendix 7
- Spatialisation Questions 7 and 8 Incorrect Responses

ANOVA
Single Factor ά = 0.05

SUMMARY

Cohort response per question	*Count*	*Sum*	*Average*	*Variance*
Column 1	11	264	24	843.4
Column 2	11	550	50	472.2
Column 3	11	898	81.64	609.25
Column 4	11	826	75.09	753.49
Column 5	11	760	69.09	956.69
Column 6	11	847	77.00	790.60
Column 7	11	398	36.18	960.76
Column 8	11	313	28.45	582.67

One Way ANOVA

Source of Variation	*SS*	*df*	*MS*	***F***	*P-value*	***F crit***
Between Groups	42242.36	7.00	6034.62	**8.09**	0.00	**2.13**
Within Groups	59690.73	80.00	746.13			
Total	101933.09	87.00				

As the F statistic (8.09) is greater than the F critical value (2.13) the Null hypothesis of equality of means is rejected and there are therefore differences in means for cohorts for correct answers to spatialisation questions 7 and 8 of the GeoTSAT questionnaire. Despite increased probability of type 1 errors, these differences were elucidated with individual t tests and recorded below. In effect, differences are largely due to age and experiences of cohorts rather than types of spatialisation difficulty exhibited.

SUMMARY of Table 7.12, Appendix 7 - Spatialisation Questions 7 and 8

(dF= 7) a = 2.365 @ 0.025 (99% confidence) and 1.895 @ a = 0.05 (95% confidence). SIMSTAT Programme (Peladreau & Lacoutre, 1993).

Comparison	**T Stat**	Reject Null Hypothesis of no significant difference if T Stat is > than ά at 95% confidence level That is, there is a significant difference in means of correct answers to questions 7 and 8 of GeoTSAT if T is > ±1.9 @ the 95% confidence level.
AC13 by AUBSEC	0.49	No
AC11 by AUBSEC	0.90	No
IS12 by AUBSEC	-0.06	No
IS10 by AUBSEC	0.81	No
IS8 by AUBSEC	-0.53	No
AC13 by AUBPRIM	1.81	No
IS12 by AUBPRIM	0.82	No
AC 11 by AUBPRIM	**3.83**	**Yes**
IS10 by AUBPRIM	1.62	No
IS8 by AUBPRIM	-0.3	No
AC13 by UCSEC	-1.4	No
AC11 by UCSEC	-1.76	No
IS12 by UCSEC	**-2.52**	**Yes**
IS10 by UCSEC	-1.06	No
IS8 by UCSEC	**-3.58**	**Yes**
AC13 by UCL1	0.67	No
AC11 by UCL1	1.09	No
IS12 by UCL1	-0.04	No
IS10 by UCL1	0.87	No
IS8 by UCL1	-0.54	No
AC13 by UCL2	**-4.53**	**Yes**
AC11 by UCL2	**-8.08**	**Yes**
IS12 by UCL2	**-5.86**	**Yes**
IS10 by UCL2	**-3.80**	**Yes**
IS8 by UCL2	**-6.65**	**Yes**
AC13 by UCPG	**-4.96**	**Yes**
AC11 by UCPG	**-5.36**	**Yes**
IS12 by UCPG	**-5.59**	**Yes**
IS10 by UCPG	**-3.7**	**Yes**
IS8 by UCPG	**-6.16**	**Yes**