TWELVE BOXES OF GRAVEL AND PLASTIC FOSSILS: CREATING A GEOLOGY 12 PROGRAMME IN A NEW SCHOOL

by

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Abstract

This thesis is a record of two research strands that have been intertwined during the development over a four year period of a classroom curriculum for an elective Geology 12 course in a new school. It discusses traditional belief systems identified as common to the practice of senior science and how one teacher wanted to challenge those beliefs to produce a working curriculum that would focus on long term learning within the framework of an externally prescribed curriculum and a provincially mandated external final exam that counted for 40% of the students mark. The teacher, working on her own in a portable for the first two years was in the unenviable position of being supplied with textbooks with a foreign focus and with supplies that as the title suggests were of little use over the long term.

By Christmas of the first year a number of major problems had been identified, these problems falling into two major categories - developing strategies for long term learning that, within the operational constraints of grade 12, would enable the students to take far more responsibility for their own learning, and second, developing a science research programme for acquiring the resources, principally through field work, that were identified as being necessary for the programme. The major concerns within these two problem areas were identified and a four year timeline was developed for implementation. On the pedagogical side, after examining some of the literature on learning, particularly that around the area of cooperative learning that has had a substantial focus in recent years in a number of local school districts, reflecting on what worked for me in terms of my practice over 27 years of science teaching, I chose to focus on the Project for Enhancing Effective Learning (PEEL), out of Monash University, Australia as my working framework for learning.

The process of developing this classroom curriculum was framed as a qualitative individual action research project over time as, within my professional life, there were no other teachers involved with the geology programme within the school, and at the same time being in a portable isolated me from my

peers–I had no choice but to be self contained and self reliant. The pedagogical side of the process saw the evolvement of a programme that differed significantly in many ways from traditional senior science teaching. This is not to say that many teachers are not already reflecting on and trying to improve practice but for most of them it is through quiet reflection, discourse and evolution much as it had been for me until this time. For me this was the first time in my career that I was able to develop a programme from the very beginning.

The thesis details the development of a multi-level learning strategy with an underlying theme being the development of more metacognitive students. The programme entails the identification of prior learning, reflective and collaborative practice, multiple processings of content and skills, peer assessment, and semi-formal reflective assessment. For many students, particularly during my first two years, most of these strategies were completely foreign to their cultural expectations of the teacher's role as dispenser of information to be regurgitated back through formal assessment. During the last two years these challenges to student thinking have been far less dramatic as I am now a known quantity in the school and the students taking my course expect to be working at becoming more independent long term learners. The programme is also built on the premise that for geology, relevant hands-on activities are an integral part of the learning process, and this other research strand is also explored and described.

This is the story of the two research strands by which a semi-independent multi-level learning environment has been developed and implemented with a high degree of hands-on activities. Although a formal assessment of the programme is almost impossible to do within the constraints of my working environment, the personal feedback that I receive from the students, parents and colleagues indicates that it has been successful.

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Preface

After teaching for many years I was still inherently dissatisfied with the level of learning exhibited by students at the end of grade 10 and later grade 12. I had dutifully been to many workshops focussing on various strategies such as instructional theory and cooperative learning as a means of improving student learning, but found that in spite of many attempts to implement such strategies long term learning showed little or no improvement. I attended many workshops guaranteed to improve my teaching but kept hearing very little about student learning. Learning to me was not just the ability to play at Trivial Pursuit regurgitating facts for prizes, i.e. passing the exam, but rather the ability to transfer skills and knowledge to new contexts, to evaluate evidence and problem solve for example. The universal panaceas that periodically come down from on high through superintendents and principals rarely worked as we in the classroom are dealing with complex humans and one size definitely does not fit all.

Although the Ministry of Education through its curriculum documents kept espousing such noble ideas as "lifelong learning", "independent learners" or "higher level thinking", as did my school district in its statements of goals, as did my own school, very little was being done to actually implement or promote the necessary changes that would be needed if such statements were to be taken seriously. As the literature indicated so strongly, secondary school science basically operated as a factory system with a highly transmissive teaching structure to reward those who could regurgitate back at the final exam. The literature further indicated that even university graduates frequently still lacked basic understandings of their discipline.

I came across concepts of constructivism and the impact prior learning had on new learning, and researched a variety of strategies that would encourage greater internalization of both concepts and their interrelationships. Using that as a basis I began to work with some of the strategies in the constructivist literature and found that students were starting to make far greater connections than before. At a workshop a number of years ago the speaker described an Australian project, the focus of which was to improve student learning and which was being driven by classroom teachers. The notion that students were capable of reflecting on their learning and making change accordingly began to suggest ways in which students could be encouraged to take much more responsibility for their own learning. Another important realization was that one time learning inevitable resulted in low level learning, learning had to occur through multiple exposures in different contexts and had to be linked to both the past and future learning. Over the course of my many years teaching junior high science these ideas were fermenting in my mind and were being implemented somewhat piecemeal as I tested them out.

In September 1997 I started at a new grade 9-12 school as the Geology 12 teacher, teaching both that course and at that level for the first time. I began to realize a few months into the course that here for the first time, that in spite of the external constraints of an imposed curriculum and a government exam, I had an opportunity to develop a whole course from the beginning that was focussed on learning. I began by critically evaluating how classroom time was being used and in terms of learning I found that much traditional practice was somewhat ineffective considering the time spent. Passing more responsibility for their own learning back to the students themselves would free up a lot of that wasted time for the implementation of newer and different activities and strategies through which greater learning would result. This was followed by a repackaging of the curriculum topics into a more learner friendly sequence moving from the here and now to the distant in both space and time, and then constructing a concept web of all the major linkages within the prescribed curriculum. This construction of an organizational matrix and the repackaging of time were a vital beginning to the process of changing practice. The class curriculum that was to be developed had to be holistic in nature encompassing multiple aspects of learning while being embedded in an overlying pragmatism that surrounds the day to day life of the classroom teacher.

This is the story of that curriculum project and the two research strands that were involved. There was the obvious pedagogical and practical research involved in developing a new concept of teaching senior science, in which the driving force was student learning rather than the final exam, as I believed that with proper learning the exam essentially would become a minor player in the course. The second strand revolved around two strong beliefs - that high level hands-on activities were to be an important part of the learning and that there had to be more relevant local and Canadian context. This part of the course development involved a great deal of geology research culminating in extensive travelling and field work that is an ongoing part of my life - I am modelling not just a role as a teacher/educator but also as a science researcher.

The text-based resources at my disposal are published in the United States and exhibit a very parochial notion of geology. Not only that, the highly stylized writing did not endear itself to my students and certainly did not encourage learning. It is certainly not a book that I am drawn to. If there was to be such a hands-on course with meaningful and relevant context then I had to develop and write a resource package that would broaden the content base and outline the activities using a variety of writing strategies that would facilitate student learning. To this end I would also write this thesis in a way that it was also more reader friendly to the classroom teacher rather than engaging in a highly stylized writing style that might be acceptable to the academy but would be potentially restrictive in terms of the day to day practitioners in the classroom

The Geology 12 programme described has evolved into a high level science course based on reflection, active processing, self evaluation, negotiation and self responsibility. Developing this programme has been one of the most exciting educational journeys in which I have been engaged during my many years as an educator. Such a programme is almost impossible to assess directly, certainly the marks on a relatively low-level final exam are not a reflection of higher level learning so I have had to rely on anecdotal evidence. The various types of feedback I receive from students and parents, and more recently my peers tells me that the programme is a resounding success and I want to now develop a similar coherent approach for each of my other courses. I believe that the whole multi-layered approach to learning is not restricted to geology and can be implemented at a variety of grade levels in different courses. I hope that you as the reader can take some of these ideas and examples and adapt them to your own teaching situation with the goal of improving overall student learning.

Erica Williams, December 2001

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I would like to acknowledge the help and encouragement of my fellow teachers, as well as the different faculty members with whom I have interacted over the last few years. In particular, thanks go to Dr. Karen Meyer, Dr. Jim Gaskell, and to Reg Wild for helping me complete this project. Special thanks go to Reg Wild who was instrumental in stirring my interest in geology many years ago.

Introduction

Returning to my school district in June 1997 after two years on leave, I was assigned to teach some Science 9 classes, and all the Earth Science 11 and Geology 12 classes at a suburban grades 9 to 12 secondary school. This was a new school, only one year old, and I was to be the geology expert even though I had never taught the senior grades before. However I had been one of the few science teachers in that district who had consistently taught the Earth and Space Science Units through Grades 8 to 10 since I entered the profession in the fall of 1970 and looked forward to the challenge. I spent part of that summer making two trips through the southern half of British Columbia brushing up on my geology of this province as well as gaining a better understanding of the role mining took in opening up this region of Canada, and still takes in terms of the provincial economy.

One trip along the Crowsnest Route passed through many reminders of copper and silver mining in the Boundary and Kootenay regions into the old coal mining areas of the Crowsnest Pass; a region that in many ways reminded me of my own childhood associations with the mining towns of South Wales, and many Welsh miners did come to this region to work in the coal mines. I was fortunate to be able to visit a modern open pit coal mining facility near Sparwood, BC and compare that with the underground mining at Blairmore in the Pass. The second trip north towards Prince George had a definite focus on modern day open pit copper mining at Highland Valley, near Kamloops, and Gibralter Mines near Williams Lake. At the time of writing, the Gibralter Mine is closed as a result of continuing low copper and other commodity prices, so I was fortunate in the timing of my visits.

Both trips were very successful in terms of collecting working specimens for my new students as well as further building my own collection of 35 mm slides and reinforced my belief that to be a good geology educator one has to both live and model a love of the subject. As I had been teaching the Earth

Science for a long time at the junior grades I had already acquired a basic rock collection of my own, always believing that samples had to be at least hand size to be useful for learning. I cannot understand how students can hope to learn anything about the nature and properties of various minerals and rocks with the tiny little samples that come with all the commercial kits.

By late August with the beginning of term only a weekend away, the portable in which I was to teach the Earth Science and Geology was not ready and although the textbooks had supposedly arrived they could not be found. I had not met any of my new colleagues in the science department except the department head and did not know what resources the school had. I had assumed that there were some as Earth Science 11 had been taught during the first year the school was open. On the first day of term a collection of assorted boxes was brought down to Portable 3, or the "Rock Shop" as I had already decided to name it. These were my new resources that were already in the school, carry overs for the most part from a nearby junior high school which had been converted to a middle school with the opening of the new secondary school.

On poking through my new found treasures I began to despair at the motley assortment of incomplete kits and sets, a museum collection of models, and a crazy mixture of yogurt, margarine and other plastic containers with the occasional beaker and glass jar, each containing small rock or mineral chips from the Geological Survey of Canada or other cmmercial kits. I think the saddest moment came when I unearthed from the depths of one box three screw top containers that each contained a poorly made set of grey plastic fossil replicas. I realized that I was on my own with no budget or extra time, just my own experience and resources to build up an active Geology 12 course with a focus on interactive learning, and a government exam at the end of the course.

In terms of the student clientele, Geology 12 is unlike any of the other senior science courses. For each of the other Grade 12 Science courses - Physics 12, Chemistry 12, and Biology 12, it is a common prerequisite that the student have passed the corresponding Grade 11 course. With Geology 12 the only prerequisite is having passed a Grade 11 science. Consequently a typical Geology 12 class has a much more diverse background in terms of the students' academic and practical knowledge than any of the other grade 12 sciences. On top of that the course is considered by many students to have the lowest status among the four grade 12 sciences. It has been my experience over the last four years that about 30% of the Geology 12 students have taken Earth Science 11 and another 50% of the class have been fortunate enough to have a complete set of Earth/Space Science experiences through grades 8 to 10. The remaining 20% have missed out on one or more of their Junior Science foundation courses. This diversity in backgrounds at such a senior level and with a government examinable course provides tremendous challenges to the Geology 12 educator.

The text that awaited me, "Earth Past and Present" by Thompson, Turk and Levin (1995), was a new listing for the updated curriculum that was mandatory as of September 1997. The text was very compressed in terms of its presentation of the bulk of the course units as 42% was taken up with various aspects of Geologic Time that were only assigned four topics out of the twenty four in the course. The book is a first year college level general geology course that is written and published in the United States and has a very parochial viewpoint towards geology. Other than a number of geological catastrophes , geological examples beyond the borders of the United States and its territories are rarely mentioned. As a geology educator in Canada, I would find this same concern if our textbooks were printed in the United Kingdom as it is only natural to focus on one's own country. But it does create a problem for the Canadian educator in terms of teaching about Canadian geology.

There also turned out to be a number of concerns with the textbook in terms of student learning. The text is very dense, with a very high reading level, and in many cases gives the appearance of a litany of definitions. It also contains a number of geological myths such as obsidian is formed by extremely rapid cooling or leads the students to acquire misconceptions such as shield volcanoes generally form volcanic islands. This last misconception has even appeared on a recent exam. The textbook is very traditional in terms of layout and presentation and its approach to learning, and has no supplementary hands-on or activity resource. Although this text was delisted in 1999 and replaced with two other choices, "Earth

Then and Now" by Montgomery and Dathe (1997), and "Physical Geology, 3rd edition" by Monroe and Wicander (1998), these alternatives in my professional opinion, still suffer from the same faults to a greater or lesser degree. Since my copies of "Earth: Past and Present" are so relatively new I cannot justify throwing them out to be replaced by other texts of doubtful improvement and at considerable cost, on average $80.00 each.

As I worked my way though the first couple of weeks in my new assignment it quickly became obvious to me that I would have to develop all the resources that I needed, that the text was too complex for the majority of students, and I had to make the course as hands-on and relevant as possible. Every weekend for the first month my small apartment living room was covered with a large sheet of cardboard on which minerals and then the different families of rocks were formed into individual little piles. As space was very limited in the portable, I decided to store these small samples in numbered re-sealable plastic bags for easy storage and inventory control. Since the Rock Shop was housed in a portable I had to be extremely inventive in my storage methods.

It also became obvious as a result of my extensive teaching experience that this was a chance to develop a course that focussed on students taking much more control of their own learning, a process by which I taught the students that learning involves making many personal choices. A student who recognizes these choices and has learned to make sensible learning decisions is well on their way to becoming a successful independent learner. This is a philosophical approach that I had been working with for a number of years at the junior high level. Here I was, the Rock Lady, in a new school with new students who had not been exposed to my methods with the opportunity to set a new standard for geology education.

I had, over time, through a multiplicity of experiences as teacher and learner, come to realize that there were a number of facets to developing a successful and independent learner. Learning takes time, means challenging previously held beliefs, and requires that the content or concepts be intellectually processed by the learner. It is a social activity that requires that students take charge of and accept responsibility for their own learning. Learning must be seen by the learner to be relevant and contextually situated, and requires multiple exposures to concepts through a variety of contexts. Learning also benefits by identifying and reprocessing mistakes. Although similar lists can be found in a variety of education texts, it would be dishonest for me to cite any specific source for my inspiration, as most of these ideas had already evolved in my thinking through many years of highly involved reflective practice.

Over 20 years ago I gave my Grade 10 students an exercise involving a pretest of their knowledge of the human reproductive organs, after these students had been taking family life/sex education courses since grade 5. The pretest demonstrated that these students who claimed to be so sexually knowledgeable were generally very unaware of the basic structure and functions of their own organs, even after these special courses. This pattern followed through consistently for the rest of the time I taught grade 10 science. I realized that whatever strategies had been used in the previous classes, little or no learning had taken place, there had been no involvement and no internal processing. The students had done well at labelling diagrams and filling in worksheets but these were totally passive activities.

When I started the Geology 12 course by doing a simple exercise mapping out some of the major physical features of the Earth, I discovered that the students had what I believe to be a lack of basic knowledge about the major surface characteristics of Canada and the larger world around them, considering that they had experienced eleven years of formal schooling. They had jumped through the relevant hoops and passed the specific sections of the various courses, but no long term learning had taken place. There was a certain personal irony in this in that many years ago I had to demonstrate my knowledge of of the history and geography of Canada before I was given my citizenship.

There certainly have been many seminal moments in my own academic journey. One of the more important was meeting Rosalind Driver at a Science Teacher's Conference at the University of British

Columbia many years ago, and being so intrigued with her notions of constructivism that two days later I made the long trip from my home in Port Coquitlam back out to the university to hear her speak again. For the first time I was introduced to the concept that students are not empty heads waiting to be filled with knowledge but rather they come to class with their own ideas of how the world works. The challenge of the teacher is to encourage the bringing out of those ideas, help the students to challenge the validity of those ideas and to then help reconstruct an understanding of a more scientific explanation. This prompted the development of a number of strategies such as Predict-Observe-Explain, or POE, to challenge student thinking. In a POE activity, students are presented with a scenario, asked to predict what will happen, and to give their reasons for their predictions. The scenario is later tested and the students then asked todescribe what they observed and revise their explanations in terms of their observations. However it is frequently difficult to challenge deeply held beliefs based on religion such as I face whenever I am teaching about geologic time.

A second inspiration was meeting up with Ian Mitchell of Monash University, one of the prime motivators behind the PEEL Project (Project for Enhancing Effective Learning), Mitchell (1997). The PEEL project focuses on learning rather than teaching, and at the same time helps to give learners the tools to take responsibility for their own learning. This project started in 1984 at a high school in Melbourne as a teacher based action research project aimed at encouraging more active learning on the part stidents. It started with twelve teachers working with five classes of students over a number of subject areas. The teachers met regularly to not only discuss among themselves different ways of developing more active learners, but equally important to support each other when strategies did not work as had been hoped. The project has since expanded to a number of other schools throughout Australia and other countries. For a number of years Ian has been coordinating and producing a series of newsletters containing articles, written by teachers, describing various strategies that the authors have developed for their classrooms

Another was standing on top of the rim of a large volcanic crater in Newberry National Volcanic

Monument in central Oregon and looking down onto a substantial obsidian lava flow. After looking at the whole flow, and later walking along a short trail across the top of the flow, I started thinking to myself that the common textbook description that obsidian formed from extremely rapid cooling just had to be wrong. I had seen demonstrations in some older videos that purported to demonstrate that rapid cooling lead to the formation of glass, but there was no possible way that this massive flow had cooled quickly enough to form volcanic glass. The crater also contained contained two smaller but still significant obsidan flows.So then came such questions as why does it form, why do texts still perpetuate this myth, how often do text writers and for that matter teachers get out into the field?

I decided that what was needed was to develop a multilayer learning process, taking into account the students' prior knowledge, but also using a variety of critical processing strategies. An important aspect of this was as much use as possible of hands-on learning rather than just text learning so resources became a significant issue, together with all the associated problems of inventory control and storage. Since this approach takes more time, I also had to look at my own control of classroom time to eliminate built in wasted time and inefficiencies.

At the end of the first week of November 2000, I received a phone call asking if I would be willing to take over an existing Geology 12 night school class. The present teacher had taken on a permanent assignment somewhere else and was no longer available. I agreed on condition that the class be held in my classroom; I had since graduated to a classroom within the main school, and although it was not a science room in the conventional sense of the word it was large and just a few metres away from the science area. When my small band of students arrived it turned out that their previous teaching and learning had been purely through bookwork and unfortunately they had had no hands-on experiences at all as the resources were just not available. Initially the specimens are used to teach mineral and rock identification. With the rocks I have multiple samples of the more common types giving the students chance to understand the potential for variation among samples. Later the specimens are used to encourage more deductive activities such as explaining the changes that have happened to a weathered sample over time. Watching them work with my specimens through the subsequent weeks reinforced my belief in the importance of hands-on work, and the justification for such approaches to learning, particularly in geology.

If I was intending to give the students as much control as possible then how did I feel about student self assessment as being part of the process. How could I do this and to what degree? In the end I decided that the students were certainly capable of self and peer assessment in the formative stages but that I would need to keep control of the summative evaluation. Putting the students in control of evaluating their day to day work freed up time traditionally spent in homework checks and corrections for example, creating time for more interactive learning.

This thesis is the story of developing a new Geology 12 programme in a new school with little or nothing in the way of school resources. It is about dealing with a much more varied clientele in terms of prior learning than the traditional science courses. The programme that has evolved focuses on a semi-independent multi-layered approach to long term learning. By semi-independent I mean that the students work in set blocks of time ranging from one to seven class periods and the associated homework time, during which they take a much greater role in organizing their learning than in a more traditional teacher-centred approach. Multi-layering leads to a minimum of four different contextual exposure to the various concepts. Furthermore, such an approach helps to prepare students for more independent lifelong learning, particularly those for whom further formal education is important. If it is to be hands-on, what does that mean for the needed resources in terms of not just their acquisition but also inventory control and storage. The curriculum is very neutral in terms of place but as all the main texts are books written by United States authors how have I integrated a Canadian context into the course. How do the students adjust to a very different approach to learning and what are the stresses and strains on them? How do other science teachers react to the processes that I have initiated and what are the stresses and strains on me as the geology teacher? I can still remember the feeling of trying not to panic that first day in the Rock

Shop portable, when I walked in on those twelve boxes of gravel and grey plastic fossils.

The process has been one of two research projects closely intertwined, the pedagogical research and implementation of metacognitive strategies to develop greater degrees of both student learning and independence, and the science research as I set out to develop a good selection of resources. Chapter 2 starts with an overview of the current geology 12 curriculum and continues with a description of the typical student in geology 12, an overview of resources, both print and physical, and concludes with a short discussion on the Geology 12 government exam. This chapter also outlines some of the constraints under which, I as a grade 12 educator, have to operate. Chapter 3 looks at some of the traditional issues that have been identified in the literature in the teaching of science at the senior grades. There is a general lack of understanding of the nature of science, lab work was generally verification exercises written up in a pseudo journal style, and the overall goal was to inculcate right answers to be regurgitated back on the exam, the real driver of the course. This chapter also lays out the individual action research approach that I developed to create a more transactional learning environment that gave a great deal more responsibility for their learning over to the students themselves. The fourth chapter discusses the issues behind developing a class curriculum and how that evolved over time. Chapter 5 develops the multilayered approach to learning based on the principle that for learning to take place the students should have been exposed to a concept multiple times in different contexts, Feik (1991). Chapter six focuses on the science research behind the development of the necessary resources that for the most part I had to create or develop. The final chapter is both a review of the four year process as well as a projection into the future in terms of what still needs to be done and future visions.

2. Overview of Geology 12

Curriculum

Geology 12 was introduced in British Columbia as a separate science course in 1977. That curriculum was broken down into four major sections or units:- Physical Geology, Historical Geology, Earth Resources, and Planetology. The units were divided into twelve Topics through which were spread 158 specific Learning Outcomes. The current Geology 12 Integrated Resource Package (IRP) which includes the prescribed Learning Outcomes was introduced in 1995, with Earth Science 11 to be implemented in September 1996 and Geology 12 in September 1997, the year in which I began to teach the course. This current IRP is organized into five units with a total of twenty topics labelled from "A" to "T". The units and topics are presented in the following order:- Earth Materials (A - F), Time and the Fossil Record (G - J), Internal Processes and Structures (K - O), Surface Processes (P - S), and Comparative Planetology (T). The letters indicate the topic numbering system, so there are 20 separate topics containing a total of 103 specific Learning Outcomes.

Although many of the core outcomes from the early curriculum were kept in the 1995 revision, some material was dropped and new material added, but the difference in the number of outcomes primarily results from a regrouping and consolidation of outcomes. Vulcanism, which had been part of the Physical Geology Unit, and Earth Resources which had been a small unit on its own were both now moved into the Earth Materials Unit. Outcomes that were dropped included the relationship of chemical bonding to structure in the silicate minerals, ecology, and various forms of pollution. Topics that were de-emphasized were eolian processes and environments, groundwater processes and environments, and many of the outcomes involving evolution and diversity. Weathering and mass wasting were more clearly defined in the revision. Like many science courses there is a large vocabulary component with over 270 direct definitions within the specified outcomes, on top of which are the many terms of the implied or hidden curriculum.

In the introduction to the 1995 IRP there seems to be an emphasis on the environment that is not reflected in either the actual outcomes or the government exam. Under the heading "The Earth Science 11 and Geology 12 Program", (p. 2), a section of four paragraphs, the first paragraph stated "Through the investigation of geologic processes, students will become aware of their role as custodians of our unique and fragile planet and develop an appreciation of the impact of human activities on both local and global environments." In the second paragraph this was reinforced with "Students will be given opportunities to apply their knowledge of geologic processes to local concerns, such as ground water quality or resource extraction, and thereby develop a greater awareness of environmental issues." Paragraph three continued with "Activities to encourage critical thinking skills are incorporated in all aspects of the program and are consistently used to enable students to question many of the land use practices currently affecting many parts of our world."

It was surprising then with such a strong environmental statement within the rationale for the course that only three outcomes, F 6, Q 3 and S 4 mention environmental concerns, and only S 4 truly has an environmental focus.

"F 6 - explain how a variety of factors (e.g., price, concentration, accessibility, size, and environmental considerations) determine whether or not it is economically feasible to extract a given occurrence of a mineral, rock, or energy resource." (p. A-17)

"Q 3 - relate such factors as load, gradient, discharge, channel shape, sediment composition, and human activities to erosion and deposition by streams." (p. A-22)

"S 4 - describe how the following human activities affect the quality and quantity of groundwater: urbanization, waste disposal, agriculture, conservation and reclamation." (p. A-23

It appears that the high regard for the environment included as such a significant part of the rationale for the course is not reflected in the actual learning outcomes.

According to an electronic bulletin of February 26, 2001 from the Ministry of Education titled "Trends in Provincial Science Examinations: 1989-1990 to 1999-2000", Geology 12 had the greatest increase in participation rate of all the sciences. However, in terms of actual numbers it was the lowest by a significant amount. Part of the reason for this may be that it is not offered in nearly as many schools in the province as the big three of physics, chemistry and biology, but also it does not have the same perceived status yet as the others–it has had a much shorter history. Geology also had the greatest percentage increase in course marks, although it was still the lowest of the four sciences just behind biology, and the greatest increase in female participation although males still outnumber females somewhat. For comparison, in chemistry the gender balance is more or less equal, in biology almost twice as many females participate than males and this is reversed in physics where slightly more than twice as many males participate.

Resources

I did not see the textbook, "Earth: Past and Present", by Thompson, Turk and Levin (1995), or the actual physical resources that were to be made available to me by the school until the portable that was to be my home for the next year at least, was ready for occupancy on the first day of the new school year. That afternoon some student helpers brought me a stack of textbooks and twelve cardboard boxes labelled Earth Science. I was to meet my students for the first time the next day, for all of us the first time we were experiencing Geology 12. Since we were on an alternate Day 1/Day 2 schedule at that time I knew that I just had to survive through two classes before the weekend. Not knowing much about the students' backgrounds, but knowing that there were likely to be some class changes during the next few days, I pulled out an old mapping exercise identifying and labelling some of the more important surface features of the Earth. This was intended to not only review the students' knowledge of major geographic features, but to also keep them busy as I struggled to make sense of the boxes and gain some planning time. I discovered, through this assignment, that the students had what I believe to be a major lack of knowledge about the major surface characteristics of British Columbia, Canada and the larger world around them, considering that they had had 11 years of formal schooling. In terms of learning geology at this level, knowledge of the locations of the major mountain ranges is not mere trivia, but is integral to any discussions of geological processes for example.

The boxes were a jumble of miscellaneous rocks from who knew where, boxes of incomplete kits, framed pictures with tiny rock chips glued in place and text so small that one needed a magnifying glass to read, containers filled with small rock and mineral sample chips from kits supplied many years earlier by the Geological Survey of Canada and other sources, some battered posters, some newer and complete sets of small rocks and minerals from the British Columbia Mining Museum, and three containers of grey plastic fossils. This was the school's contribution–twelve boxes of gravel and plastic fossils. My contribution consisted of a large poster collection that had lived in tubes under my bed for the last year, about twenty five hand sized rocks which I had to collect from my old school (I had left them there while I had been on leave) and a reasonable collection of fossils that I had collected on and off over my teaching career, some containers of sands, some samples I had collected on two extended trips during that summer and about 1000 35 mm slides of geological features from my junior science days.

Every weekend for the first month my small apartment's living room was covered with a large sheet of cardboard on which minerals and then the different families of rocks were formed into individual little piles. As space was very limited in the portable, I decided to store these small samples in numbered re-sealable plastic bags for easy storage and inventory control. Since the Rock Shop, as I had designated my classroom, was housed in a portable I had to be extremely inventive in my storage methods. Each collection of small chips, minerals, plutonic rocks, volcanic rocks, sedimentary rocks, and metamorphic rocks could be stored in their individual plastic bags in a cut down labelled paper box that could be stacked two high on the shelves in the little storage space available. The larger specimens were permanently laid out on the top of the book shelves that were under the windows where they were readily available.

The text I was given for student use, "Earth: Past and Present" by Thompson, Turk and Levin, is a college level introductory geology text written and published in the United States of America, that was approved for use in British Columbia schools just a few months before we purchased them. As well as being solidly grounded in the geology of the United States with the rest of the world barely mentioned, it has a heavy emphasis on historical geology, over 40% of the text, that is of little or no use to our current British Columbia curriculum. The less than 60% of the text that is usable is very dense and in many cases gives the appearance of a litany of definitions, to the point that even I, as the geology teacher, do not obtain any pleasure from reading it. Barba, Pang and Cruz, (1993) sum up my feelings for this particular text when they stated "Historically, science textbooks have been at best described as packed with facts but lacking in concepts, and at worst condemned as inaccurate, poorly organized and boring." (p. 15). My experience over the last four years is that the students do not like this textbook and find it very difficult reading, even though it has many pretty colour pictures. However, in terms of the current geology texts, I am inclined to agree with Barba, Pang and Cruz (1993) when they continued "Difficulties students encounter in comprehending modern science textbooks, however, may be more attributable to their being reader "unfriendly" rather than their being too difficult for the age group intended." (p. 15).

In spite of a call by the Science Council of Canada (1984) that "The Science Council believes that the science that is taught to young Canadians should be set in a Canadian context and that this context should include both historical and social aspects. " (p. 40), the recently approved Geology 12 texts, Montgomery et al. (1997), and Monroe et al. (1998), also suffer from a heavy United States emphasis. These texts all contain a plethora of photographs, frequently with no sense of scale, an important factor when supposedly looking at a close up of a rock to show specific detail, although Montgomery and Dathe does do a better job in this regard than either Thompson et al. (1995), or Monroe et al. There is also little or no sense of direction in wide view photographs, and in coastal pictures showing longshore transport of material along a beach face, the direction is important. Such pictures add colour but do little to enhance learning, either by placing the subject in context or by clarifying the detail. There is little attempt to use such strategies as labeling key aspects of the photograph or overprinting photographs with text to reinforce concepts as in done so well by Gadd (1999) in his "Handbook of the Canadian Rockies". In his handbook, Gadd takes pictures from different parts of the Rockies and overprints them with lines and arrows to show the specific thrust fault boundaries and the direction of movement. Monroe et al. (1998) use the technique of having a line drawing and the comparable photograph side by side in their section on structural geology. This technique enables the learner to pick out the particular features being discussed in the line drawing and then relate to the real world of the photograph. Another technique for facilitating learning is to present comparative information in both text and chart form, but this is rarely done.

Apart from the density of the text and lack of Canadian context each chapter is treated as a separate entity on its own with very little in the way of cross-connections or reinforcing of earlier knowledge between chapters. Each chapter is broken down into numbered sub-topics between which connections are sometimes made. However, the numbering of these subtopics, which does not occur in the currently recommended texts by Montgomery and Dathe (1997), and Monroe et al. (1998), does make it easier as a teacher to assign specific readings. "Earth Past and Present" is very traditional in terms of layout and presentation and its approach to learning, and if a supplementary hands-on or activity resource has been produced, it is not available in the school.

Although much of the material in the three textbooks mentioned is generic, not one of the books has a bibliography. Monroe et al. (1998) has a section of "Suggestions for Further Reading" at the end of each chapter, as does Montgomery et al. (1997), although the latter's choices for readings are somewhat dated, while Thompson et al. (1995) has no such section. This lack of a bibliography just continues to reinforce the notion that the text is 'all knowing' and has all the answers. The review questions at the end of each chapter are the low level recall variety in Monroe et al., and of slightly higher quality in the other two books, although still focussed on content recall.

It is becoming more common to include a CD-ROM disc with some geology texts but I have not found them to be very useful. The textbook CD-ROM's with which I have had some experience have generally been nothing more than a repackaging of the text material with some extra pictures and questions. A couple of the exercises on the Monroe et al. (1998) CD-ROM involved tiny little pictures that were extremely hard to interpret. I found much of the text on this particular CD-ROM to be at quite a low content level, compared to the textbook. Although this might be suitable for slower learners it would not satisfy the current Geology 12 learning outcomes. I frequently have difficulty even opening up the older CD-ROM's as it is based on older technology, or cannot open up certain parts as the technology is very specific, or it is PC based and will not work on a Macintosh system. Even though "Earth: Past and Present" is no longer listed as an approved text, my copies are so relatively new I cannot justify throwing them out to be replaced by other texts of doubtful improvement and at considerable cost, on average $80.00 each.

Students

In my current school it is the general practice to insist that the students have acquired credit for the equivalent grade 11 course before taking the traditional government examinable science courses in grade 12. For the Geology 12 course, there is no requirement for such a specific prerequisite, only that the students have credit for any science 11 course, and in practice over the last four years only about 30% of the students have taken Earth Science 11. About another 50% of the students have been exposed to the Earth and Space Science components of Grades 8 to 10, while the remaining 20% are deficient in one or more of those courses. Thus, in terms of background knowledge there is a much more varied clientele, with large knowledge gaps, entering Geology 12 than would be entering the more traditional science courses.

During the last four years the class has consisted of 60 to 65% girls, somewhat unbalanced in terms of gender but not nearly as skewed as Physics 12, with a heavy male bias, or Biology 12 with a heavy female bias. Each year, the geology class has always been first in a non-rotating timetable. For the first two years we had a 7:30 a.m. start, with the last two years starting at 8:45 a.m. This fixed first period start has, in my judgment, been the cause of a high degree of student absenteeism from this class, mostly due to sleeping in, which has had a negative impact of the learning of a number of the students. I am caught between wanting them to do well in the course, yet at the same time making them take responsibility for their own choices. This is an example of how the structural organization of the school can have a significant impact on student learning.

A further complicating factor is that Geology 12 is considered by the students to have the lowest status among the grade 12 science courses and they are not ready for the high level of classwork and learning that I demand of them. These considerations of attitude and knowledge are important as all the students have to be brought up to a high knowledge level by the end of the year or semester for them to have the best chance of success in the Geology 12 exam, a much greater challenge in Geology 12 than the other sciences. The students come from a typical Vancouver suburb with traditional school experiences. They fit into the pattern of many students who are described by Baird and Mitchell (1997) as "Students have definite, conservative and restricted views about what constitutes learning and what are appropriate teacher and student classroom behaviours." (p. 215).

Assessment

Although there is regular class based assessment, Geology 12, like the other core sciences of biology, chemistry, and physics, has an external government exam at the end of the course that counts for 40% of a student's final grade. Unlike the other three science courses that have exams at the end of January as well as the end of June, Geology 12 only has the one exam in June. Thus there is really only one chance in the year to take the exam and this puts extra pressure on the students to succeed. A student in the other sciences, particularly in a semestered school, can write an exam in January and then again in June to improve the exam component of their mark. I realize that there is a supplemental exam in August for those who failed or did not do as well as they expected in June, but the reality is there are fewer exam options in the geology course, and more pressure on both student and teacher.

The exam consists of 55 multiple choice questions, worth one mark each, the remaining 45 marks coming from short answer questions. Each question is assigned a cognitive level code and is correlated with the learning outcomes. In assessing each exam during the last four years I find that the formal answer key assigns most of the multiple choice questions at the understanding cognitive level with a few, five to seven, at the lowest or knowledge level and about the same number at the higher order thinking level. However, in each of the last four government exams in which my students have participated there was an internal motivation on my part to critically evaluate each exam. I would have downgraded the cognitive level significantly and would assign most questions to the knowledge level, about fifteen to the understanding level and barely two or three at the higher order thinking level. Thus the exam becomes significantly focussed on recall of knowledge rather than a significant assessment of understanding. This again has implications for teaching and learning, particularly as in recent years outside bodies have taken upon themselves to publish and rank secondary schools in terms of their exam performances.

In British Columbia today, Geology 12 is a senior academic science course with an externally prescribed curriculum and which, in my professional judgment, has an external low-level regurgitive exam as a significant component of student assessment. The prescribed curriculum has 103 direct learning outcomes some which have carried over from 1977 and are now dated, and one which has a significant error. The structural organization of the curriculum in terms of the presentation sequence of topics may not necessarily lead to effective learning. The students entering the course tend to have a more varied knowledge base than in the more traditional science courses. Furthermore, for the first two years I was teaching the course the students tended to have very traditional expectations of their own roles and the teacher's role in terms of student learning. The authorized texts tend to be first year college level texts from the United States, and can generally be described as reader unfriendly. The texts contain content errors around the formation of obsidian or the nature of shield volcanoes, for example, that I do not expect to find in modern textbooks. The texts tend to lead to passive learning with mostly low-level recall type questions at the end of each chapter. These particular texts are also extremely parochial and the rest of the world does not really exist - so much for calls for local and Canadian content. In the next chapter I will explore these and other issues.

3. Issues and Practice

The last time in my teaching career at which I had to take on a significant new course was in the early 1970's when I was asked to teach Grade 9 math. I was given outlines, worksheets and tests as well as friendly advice by the other grade 9 math teacher's. I had not been teaching long and was glad of the help. Over the years I had constantly challenged my practice in order to develop better methods for facilitating student learning, and once I had the understandings of the basics of a course, particularly in the junior sciences, it became an evolutionary and incremental process of constant change. Even if my peers did not enthusiastically agree with my ideas there were at least other teachers of the same subject with whom I could bounce around these ideas.

At this current school I was for the first time in many years faced with the challenge of starting up a whole new course for me, but more than that I was the Geology "expert", there were no convenient subject peers for a quick discussion, or to scrounge worksheets or tests. As already indicated I had a chance that I had never had before to develop from the ground up a completely new course that focussed on learning. The course was not just new for me as a teacher but it also had a new provincial curriculum. This chapter reviews some of the issues with teacher and student beliefs, texts, resources, context and learning that I would have to challenge if I wanted to take this opportunity for change.

In his book, The Reflective Practitioner, Schön (1982) introduced the metaphor of the high ground, that neat and tidy place of modernistic thought, compared to the swamp, that messy place of the real world. Prior to the reality of that Tuesday afternoon it would have been assumed that I, with all my experience, would be able to adjust to a new school, new courses, new expectations to do what is necessary by following prescribed steps handed down from the high ground of prescribed curricula, textbooks, teacher's guides and a government exam. The real world of change is the messy world of the swamp in which people have to work together, reflecting on the pathways they are taking as they help and support their fellow travellers. And I was well and truly in the swamp, by myself as the geology expert, with only a great deal of experience and desire to change the way a typical grade 12 science course had been taught to help me through the journey. Apart from the two Geology 12 classes I also had three Earth Science 11 classes, also a completely new course for me, and two Science 9 classes, which although not completely new had just undergone a significant curriculum revision. Since I had had a major role in that revision, there was also pressure on me to model the intents of that new approach to Science 9 - the swamp was all too real.

Traditional Science Teaching

It has been my observation over many years of teaching that the general approach at the Grade 11 and 12 levels was to treat the classes as though they were in a Junior College and that teaching was done predominately by lecture, answering questions and an occasional activity that had to be written up according to the stylized format that I had been taught many years earlier. It had always struck me, primarily from my own many experiences as a victim, that this was totally passive, very low learning at the recall level. I was not asked to internalize any of the knowledge, to process or repackage that knowledge in new ways, to analyse for bigger concepts and links–just recall and regurgitate for the next test. At each level I was just regurgitating what the teacher, instructor, or professor had preprocessed and preordained. So much of my own secondary and post secondary experiences had been at this level and in terms of the American Association for the Advancement of Science's 1993 definition that "Learning means using what one already knows to make sense out of new experiences, not just storing the new information in ones head", this traditional approach was a failure.

In their book "Teaching as a Subversive Activity" (1969) Postman and Weingartner, reflecting on the historical parallels between the public school system and factory-based mass production stated

> In fact, the similarities between mass production industries and most existing school environments are striking: five-day week, seven-hour day, one hour for lunch, careful division of labour for both teachers and students, a high premium on conformity and a corresponding suspicion of originality (or any deviant behaviour), and most significantly, the administration's concern for product rather than process. But the larger point is that the sequential curriculum is inadequate because students are not sequential: most significant learning processes do not occur in linear, compartmentalized sequences. (p. 30)

Twenty five years later, Hargreaves (1994) summed up how little schools had really changed when he indicated

> Modern school systems, . . . , emerged as factory-like systems of mass education designed to meet the needs of manufacturing and heavy industry. They processed pupils in batches, segregated them into age-graded cohorts called classes or standards, taught them a standardized course or curriculum, and did this through teacher-centred methods of lecturing, recitation, question-and-answer and seatwork. (p. 27)

Boomer (1992) made a similar point when he argued

> The education system is subject to the educational myths of society (deified into theories in the universities); the teachers are subjected to the myths of the system (reified into curriculum guides, textbooks, standardized test and public examinations); and the children are subject to teachers who choreograph all the myths in subjects, each educational genre with its own ritual, language, sequences and decor and each with its own value (e.g. classsical physics is worth more than popular art, which is worth more than punk-rock, sex education). (p. 5)

What I still find disconcerting is that I started my teaching career in 1970, one year after Postman and Weingartner's "Teaching as a Subversive Activity" was published, and now, over thirty years later little or no fundamental change in the structure of the system has taken place. Certainly the current grade 11 and 12 physics and chemistry courses have changed little in either content or methodology during the more than forty years since I took them as a student. I use the metaphor of an old Model T Ford car in terms of these traditional science courses. Over the years the car has not been restored so much as modernized. It now has a radio, radial tires, a global positioning system and a new paint job, but no matter how much we gloss it up we still have an old car. The classrooms of today have videos, computers, internet access, and textbooks with colour pictures but underneath all that little if anything has changed in terms of either content or process.

There is more pressure today on the grade 12 teacher of today in terms of the importance of the government exam as school summaries of these marks are now published in the newspapers. In spite of the excuses that this will improve standards I see my peers focussing more and more on teaching to get the best exam marks possible, consequently reducing the time spent on lab work in science as this is not on the exam anyway. I realize that I am speaking ingeneral terms as there always have been, and always will be, that small band of individuals who are trying to effect change, at least within their own classrooms. However we still have the same apocryphal stories going around of the science student graduating from university still not understanding basic concepts in his or her discipline, but these students passed all their exams.

Even if the course content and process in the traditional science courses has not undergone any signifcant change, there have been noticeable changes in the student body since I started teaching in 1970. The students of today are much more varied in their abilities as more of them are staying in school since many of the low-level jobs that existed thirty years ago have disappeared and are not out there anymore. Many more senior students are working, and working longer hours–we have some grade 12 students putting in a full 35 h work week and at the same time trying to keep up with their school work. There are social pressures today that did not exist in those earlier times. In the 1970's the issues with drugs seemed to be around smoking and alcohol, cocaine and heroine were unheard of in the suburbs. For better or for worse families tended to stay together, whereas today we see many more single-parent and blended families. There is much more exposure to violence today through films, videos and games compared to earlier times. All of these issues, plus many more I have not mentioned, are brought to the classroom and inevitable impact on student learning.

As a society, and as an educational culture, we have been living with and teaching a reductionist view of science that has stretched over three hundred years from the times of Descartes. The literature informs us that science teachers' have been traditionally trained in a mechanistic view of science, frequently focussing on single subjects that leads to problematic views of both the nature of science and the so-called scientific method. In his book "The Turning Point" Capra described this development of mechanistic and reductionist thought during the seventeenth, eighteenth and nineteenth centuries when he stated

> Matter was thought to be the basis of all existence, and the material world was seen as a multitude of separate objects assembled into a huge machine. Like human-made machines, the cosmic machine was thought to consist of elementary parts. Consequently it was believed that complex phenomena could always be understood by reducing them to their basic building blocks and by looking at the mechanisms through which these interacted. This attitude, known as reductionism, has become so deeply ingrained in our culture that it has often been identified with the scientific method. (p. 47)

In terms of science education and this mechanistic/reductionist view Gallagher (1991) is extremely blunt when he stated

> Moreover, secondary science teachers have a distorted understanding of the nature of science because their scientific education has focussed on the body of knowledge of science, and it has given very little emphasis to the processes by which scientific knowledge is developed and validated. (p. 132)

Frequently teachers hold many erroneous views of both content and process that are in turn passed on to their students. Kyle et al. (1991) in their theme paper for the National Science Teachers' Association, described the mythology inherent in traditional science teaching as follows.

> For example, traditional science experiences often lead students to constructing a distorted view of

the scientific enterprise, such that they believe: (a) science is a collection of facts to be memorized; (b) all the information in the science textbook is true; (c) the sum total of scientific knowledge is known; and (d) science is a quantitative, value-free, empirical discipline. Moreover, students often fail to understand that: (a) science proceeds by fits and starts; (b) science is inherently open-ended and exploratory and that ideas based on evidence are still fallible; (c) scientific theories are enhanced through a process of sharing, debating, and consensus building; and (d) continual inquiry is a fundamental attribute of the scientific enterprise. (p. 414)

In terms of their understanding of the nature of science, teachers generally have a lack of knowledge and believe that science is a hierarchical body of rigid facts that was empirically developed through the application of the so-called scientific method, (Lakin and Wellington, 1994). Teachers come to class with a multitude of conceptions regarding both their understanding of the nature of science as well as their understanding of the concepts and process that they are about to teach, Hewson, Kirby, andCook (1995). There is a strong connection between science, math and technology but not with the humanities, leading to an elitist view of science. Science teachers generally believe that scientific knowledge is fixed and does not change and that scientific research is not tentative, (Lederman, 1992; Orpwood and Souque, 1985; and Pomeroy, 1993). In all the content areas, teachers frequently hold basic misconceptions based on outdated or mythic knowledge. So deep are these conceptions of 'right' that many teachers are uncomfortable with types of activities and evaluations where the answer is open-ended or problematic, (Bateson et al. 1991; and Zeidler, Lederman and Taylor 1992).

There seems to be strong support for the concept of the scientific method, even though such a method is an artificial construct, (Millar and Driver, 1987) that has, to use Boomer's (1992) term, been "reified" into the culture of science teaching. The "method" is nothing more than basic applications of problem solving that are typical of most areas of life, but it does in my opinion support the elitist views of science held by many teachers. Part of this mythology around the scientific method is to also insist that students write their so-called experiments in the impersonal passive voice. This was the way I was trained in school science in the 1950's and 1960's and was reinforced to me by the senior science teacher in the school at which I started my own teaching career in the 1970. Sheldrake (2001) complained

> When I was going to school, my science teachers made me write in the passive voice, but I had no idea it was still going on. Ever since I was a graduate student at Cambridge, I have thought that the active voice–"I did"–far more appropriate in scientific writing than the passive–"it was done". Experiments do not mysteriously unfold in front of impersonal observers. People do science, and to portray it as a human activity is not to diminish it but to show it as it is. (p.48)

As Bruner (1985) so succinctly summarizes, each one of the students in a class learns in an infinite variety of ways that change through such variables as the time of day, the context of the learning, the personal meaningfulness of the material, the behaviour of the teacher in the formal or informal setting or the general sense of wellness. Each also comes to class bearing ownership of a multiplicity of misconceptions and self-perceived rightness of dogma, engrained through about 12 years of societal and school conditioning. Many students have similar beliefs to their teachers, thinking that scientific knowledge is a faithful representation of the world and that what is written in their texts is absolute, (Lederman, 1992). Both teachers and students frequently do not understand that knowledge is created in a social context. In the opening sentences of "The Politics of the Textbook" (1991), Apple and Christian-Smith stated "Reality does not stalk around with a label. What something is, what it does, one's evaluation of it, all this is not naturally preordained. It is socially constructed." (p. 1). Harding, (1986) is particularly succinct when she described the social, historical and cultural implications underpinning our notions of science ". . . natural science is a social phenomena. It has been created, developed, and given social significance at particular moments in history in particular cultures". (p. 84)

Postman, N. and Weingartner, C. (1969) put this another way when they described how questioning is important in this construction of knowledge

Consider for example where "knowledge" comes from. It isn't just *there* in a book waiting for someone to come along and "learn" it. Knowledge is produced in response to questions. And new knowledge results from the asking of new questions; quite often new questions about old questions. Here is the point: *Once you have learned how to ask questions-relevant and appropriate and substantial questions-you have learned how to learn and no one can keep you from learning whatever you want or need to know.* Let us remind you, for a moment, of the process that characterizes school environments: what students are restricted (solely and even vengefully) is the process of memorizing (partially and temporarily) somebody else's answers to somebody else's questions. (p. 23)

Texts and their associated support materials are frequently implicated in the continued propagation of misunderstandings and distortions of truth, or at least perceptions of truth, in school science, Apple (1992). Harriet Tyson-Bernstein further added "Although there are some good textbooks on the market, publishers and editors are virtually compelled by public policies and practices to create textbooks that confuse students with non sequiturs, that mislead them with misinformation, and that profoundly bore them with pointlessly arid writing." (Apple and Smith, p. 5).

Common distortions in recent geology texts occur regularly, either as errors of questionable fact such as statements to the effect that obsidian is formed from such rapid cooling of lava that the atoms remain disordered as in glass–this occurs in the textbook I use, Thompson et al. (1995), as well as the two recently approved texts by Montgomery et al. (1997), and Monroe et al. (1998). I remember standing on top of a large obsidian lava flow in central Oregon and thinking to myself that the textbook description that obsidian formed from extremely rapid cooling had to be wrong–there was no possible way that this massive flow had cooled quickly enough to form this volcanic glass. So then came such questions that Postman and Weingartner described such as why does it form, why do texts still perpetuate this myth, how often do text writers and for that matter teachers get out into the field? The other common errors are errors of generalization from the particular, for example in which it is inferred that since the shield volcanoes of the Hawaiian Islands are formed from magma reservoirs that sit on an intra-plate hot spot, then all shield volcanoes are formed in exactly the same way. This second example has even found its way into a recent government exam, even though there are many shield volcanoes in the Cascade Volcanic Range of Western North America that lies above a subduction zone far from any intraplate hot spot.

Texts, and their associated materials that are frequently presented as a "complete teaching package", are the main source of information for many teachers as well as the various assessment tools they use, (Seymour and Longden 1991; Gallagher 1991; and Orpwood and Souque 1985). In terms of a specific Canadian context, Orpwood and Souque went on to state

> Senior-years teachers view science as a system of exact numbers, highly organized bodies of information and specialized terminology. Their concern is to provide students with the notes and with the practice in solving problems that will result in high marks on examinations and allow the student to move through high school to university. Work in the lab is directed towards *illustrating* facts and theories presented in the classroom, *confirming* what is discussed in class. Activities are designed to develop in students habits of diligence, self-reliance, and tidiness. Students are encouraged to become systematic and objective." (p. 23)

When discussing science in the senior years, the Science Council of Canada (1994) stated "The "right answer" counts most, and therefore, answering the questions in the "right" way takes precedence over inquiries into the real meaning of problems." (p. 31) It is interesting to note that the Science Council's discussions around senior science refer to the traditional courses of biology, chemistry and physics. This is not surprising as British Columbia and Newfoundland are the only provinces that offer a grade 12 course in geology.

Some of the specific criticisms of these teaching materials are the rigidity and conformity to the culture of school science, an emphasis on memorization and terminology, little attempt to place into a bigger self or societal context, frequently obsessed with the rigidity of the myth of the scientific method, and the tendency to absoluteness or rightness. Other sources of misinformation include library books, non-print resources - videos, films, CD-ROMs, the internet - and even the curriculum guides themselves. The current Geology 12 prescribed learning outcomes include one that refers to biological weathering even though such a term has been out of fashion for many years.

The myths around the nature of science are also reinforced by common assessment processes used by science teachers' that reinforce the rigidity and rightness of answers. The value of such practices is questioned by Rutherford (1993) in a Project 2061 newsletter in which he argued

> Teachers daily test, informally, what students do and do not seem to be able to learn. Such evidence is extremely valuable but for understandable reasons is only suggestive rather than certain. Consider some of the limitations:
>
> Teachers have little time available for conducting careful assessment of student learning.
>
> Teachers rarely have the opportunity to check their experience with other teachers who are trying to teach the same concepts and skills, nor do they have regular access to consultants who can help them analyze their experience in the light of research on learning.
>
> Traditional testing methods do not reveal what students really understand or are able to do, especially with regard to learning richly interconnected concepts and developing higher-order thinking skills.
>
> Positive results can be misleading: students' ignorance (or misunderstanding) is often masked by their ability to memorize the right words.
>
> Negative results can also be misleading: because so many variables are operating in the learning process - teacher and parent expectations, the learning environment, the methods and materials used, the previous knowledge, misconceptions and experience of individual learners, and more - the failure of students to learn something does not mean that they could not do so under different circumstances. (p. 1)

This further suggests that traditional assessment strategies not only reinforce particular teacher and student behaviour patterns around right answers but that such testing masks the real learning that has taken place. The above views tend to be reinforced by science teachers' limited training in the skills needed to use teaching and learning strategies that focus on higher learning rather than low level recall as wel as the tendency to use content recall tests with limited use of open ended problems or more practical types of assessment as reported by the following B. C. Assessment reports, Hobbs et al. (1978), Taylor et a.l (1982) and Bateson et al. (1991).

So by the fall of 1997, with the application of a new curriculum, it seems that we have a teacher population that is essentially textbook focussed, has many misconceptions of the nature of science, reinforces right answers, and has a limited repertoire of strategies, a view that is supported by my own experiences. The 1996 geology curriculum can be quickly destroyed through transmissive teaching from one or more of the recommended texts, continuing as Orpwood and Souque (1985) state "a series of disconnected sterile bland boring chapters". This in summary was the culture within which I was expected to teach Geology 12, a culture that was traditional in its outlook towards teaching and learning. Teaching was to primarily lecture with paper and pencil testing that expected right answers. Science was absolute and correct and was all about regurgitating content, and by grade twelve the students themselves were well and truly indoctrinated into this expectation. How can I, as a teacher, break down that dogma, those misconceptions and the mythconceptions buried within the consciousness of each student? That in my mind was to become an integral part of the process by which the learner is making personal meaning of new understandings of the potential richness and excitement of science, particularly geology. If I was to change the way in which I wanted to teach geology 12, I had to be prepared to challenge and work around these traditional ideas.

Learning and Metacognition

A great deal of argument has ranged concerning the nature of children's learning since Driver and Easley's (1978) landmark paper on the perspectives held by adolescents in the U. K. in terms of their understanding of science knowledge and concepts. For this part of the discussion I will use Fensham, Gunstone and White's (1994) definition that a constructivist view of learning has as "its fundamental principle that people construct their own meanings for experiences and for anything told them. The constructed meaning depends on the person's existing knowledge, and since it is inevitable that people have had different experiences and have heard or read different things, all have different (though often similar) meanings for any concept." (p. 5). Other sources of alternate conceptions are the cultural environment within both the school and the culture of the surrounding society through the popular media and television. Within the school, personal relationships and gender balance in the classroom, the tendency to follow the peer groups and use of language will all impact on the students' motivation to learn and the ability to accept alternate explanations (Solomon 1987).

In recent years the debate has shifted beyond constructivism per se to other aspects of learning such as socioculturalism in which meaning is socially constructed, Cobb, P (1994), and situated cognition in which the learning needs to be situated in a context familiar to the learner, Brown, Collins and Dugard (1989), Hennessy (1993) and Harly (1993). In my experience I would suggest that all three aspects are important considerations within the learning environment and are intimately entwined with each other. On top of these are the personal sense of motivation, Solomon (1986) or desire to learn on the part of the learner, that is inexorably linked to such factors as their personal relationships, stress, and home and school environments.

The construction of personal meanings does not mean that students can create their own theories and that they will always be 'right' in view of the problematic nature of science, but it does mean that real learning involves the shift of personal meaning towards those that are considered to be more scientifically acceptable, Driver et al (1994). Parroting the teacher's scientifically acceptable answers does not mean that conceptions have changed and understanding has occurred, even though the students frequently pass the exams. In terms of Geology 12, that shift had to be more than scientifically acceptable, it had to also be towards what will give the right answer on the external exam even in cases where there is little congruence between the scientific view and the exam question. I also have the bizarre problem with a couple of learning outcomes of having to teach misconceptions in case questions on these topics appear on the exam.

In terms of classroom teaching we must not only be aware of the social context, Cobb, P. (1994) and Driver, R. et al (1994), but also the possibility of most students possessing persistent misconceptions, Solomon, J. (1994), but can we be sure that we understand the nature of these misconceptions. Language is very personal, and has significantly different meanings for the players involved in people's learning, the teacher and parent communicate differently, Roberts, V. (1989) as well as do students and teachers, as can be seen from transcripts of students' discourse among themselves and between themselves and the teacher. Not only is the language different but the idea that as well-educated adults we can fully interpret the meaning given to concepts by students is to my mind extremely problematic–we can never put ourselves in not just the mind, but the whole construct of what it means to be an adolescent learning science within the context of the current social culture. Certainly I have to struggle at times with my younger students to begin to understand their alternate uses of language before I can even begin to understand their conceptual challenges. Overlying this oral discourse and the potential for communication problems, there is a far greater language gap between the students use of language and the highly stylized "reader unfriendly" language in their textbooks. However, in my experience over the last four years working with senior students, Geology 12 is an elective course so there is some inherent internal motivation to learn. As this age group is at the stage of young adulthood their language skills are more fluent and the students are better able to verbalize their conceptional difficulties, but even then there are times when I struggle to make sense of a student's concerns.

The traditional power position of the teacher assumes another dimension in that for many teachers, they themselves do not have an adequate understanding of the nature of science. So we have the potential for one set of mythologies challenging the other with result that the teacher's view is usually subsumed by the student for the purposes of the course but may only be partially assimilated into the student's own conceptual understanding. These false student views are further reinforced and confused by their culture and environment, their own personal constructs of science and the multitude of errors commonly presented in science texts; errors such as omission, bias or distortion through gross oversimplification, errors that contribute to the construction of those very persistent misconceptions, and even errors around the politics of the jurisdiction in which they will be used.

In terms of Geology 12, the early topics based on concrete experience, such as working with minerals and rocks, have relatively few difficulties in understanding. These topics are real, immediate and hands-on; galena is the densest of the common minerals, quartz is the hardest common mineral, plutonic rocks have visible crystals, sandstone is cemented sand particles for example. As one moves further away from this immediate experiental learning conceptual difficulties increase as do alternate explanations, with the greatest difficulties occurring the further back in time and hidden space. Thus in the study of fossils and tectonics, students are much more likely to hold alternate conceptions than they do for weathering and erosion, which in turn create more difficulties in concept understanding than minerals and rocks.

During the fall of 1991 I came across a small article in the Washington State Science Teacher's Journal about the nature of learning in which Feik argued

> Concepts cannot be taught. They are a personal developmental process. The teacher does not teach them, but must facilitate the development of them. Multiple experiences with concepts are necessary. Practice must be provided to develop skills. The minimum number of learning

experiences needs to be five with the greatest learning occurring when they are in different contexts.

Concrete experience, or hands-on learning, is especially important in the initial stages of concept development, regardless of the age of the learner. Passive learning does not work. Learning has to be as active as possible - learning and understanding does not occur until the learner has internalized and taken ownership of the concepts. You cannot teach somebody to ride a bike by reading about it, painting it, memorizing the parts, or finding out how many types there are, but by riding it. Give the learner room to make mistakes, but be there to help them accept that mistakes are a normal part of learning and not to be afraid of them.

As a clarification of hands-on activities, I agree with "Benchmarks for Science Literacy" (1993) when the authors noted that "Hands on experience is important but does not guarantee meaningfulness. It is possible to have rooms full of students doing interesting and enjoyable hands-on work that leads nowhere conceptually." (p. 319). Frequently in the past this has been the level at which many of the traditional activities of junior science have operated. The "Benchmarks" authors go on to say "hands-on activities contribute most to learning when they are part of a well-thought-out plan for how students will learn over time." (p. 320) Feik's comments had a significant impact on my own personal theorizing at the time and during the early 1990's I worked at trying to implement a learning based approach to my junior science teaching. On being asked to teach Geology 12 I realized that I had an opportunity to design a programme in which my demands and expectations would take the course beyond traditional memorization and regurgitation into the realm of long term learning.

A number of British Columbia school district have, over the years, invested a great deal of effort at encouraging teachers to use a variety of co-operative learning methods, developed for example by Johnson, Johnson and Holobec (1986) and Slavin (1981) as a way of improving student learning and test performance. One traditional advantage of science teaching in British Columbia has been that it has a more than thirty year tradition of significant group work, particularly around the laboratory activities, but not always as structured or formalized cooperative learning groups. While I believe that it is important for both students and teachers to have some basic understanding of group functioning and processes, I am not convinced that strategies such as STAD (Student Teams Achievement Divisions), TGT (Teams Games Tournament), Jigsaw and Concept Attainment really contribute to significant conceptual understanding.

As Lester (1992) stated "The teaching and learning that goes on in cooperative groups, chiefly characterized by transmission, memorization, and regurgitation, is no different from the teaching and learning that goes on in whole class groups." (p. 199). Hargreaves (1994) stated that compared to "more dangerous, spontaneous, desire-laden forms of student collaboration in the classroom ..."(the very processes that I have been trying to develop in my Geology 12 classes) " Cooperative learning is then inserted and inscribed (into classroom teaching and learning) as a contrived and controlled set of collaborative structures, practices and behaviors with its own special language: ... It becomes its own self-contained and self-affirming system - a safe simulation of the more spontaneous forms of student collaboration which the school and its teachers have already eradicated." (p. 80) (my insertion).

After attending many workshops and working through co-operative learning strategies with other teachers and with my own students at different times in my long career, I agree with Lester and Hargreaves and feel that in many cases these strategies just reinforce simple content learning and recall and do not reach down to the conceptual challenges that are inherent in many constructivist strategies. Furthermore it has been my experience that cooperative learning strategies are time consuming for the level of learning that results, and in a course such as Geology 12 in which the prescribed learning outcomes are externally imposed and an external low-level content exam is a significant part of the students' final mark I cannot afford the excesses of time required in learning low-level content through cooperative learning techniques. It is interesting to note that traditional cooperative learning strategies are not even mentioned by Fensham, Gunstone and White (1994) in their book on science content and constructivism.

As outlined earlier, the PEEL project (Mitchell, 1997) focuses on student learning rather than teaching and at the same time give learners the tools to take responsibility for their own learning. At the same time that I became interested in the PEEL approach, I started on a regular basis to use constructivist learning strategies such as discrepant events, concept mapping, mind mapping, venn diagrams, POE (Predict, Observe, Explain) and translation tasks among others, Novak and Gowan (1984), Needham and Hill (1987), Mitchell and Mitchell (1992) and Smith, Blakeslee and Anderson (1993). Over the last fifteen years I had practiced many of these teaching and learning techniques with my junior science students, but during occasions when I was able to meet with like-minded peers, found very little was being done at the senior grades. I have periodically given workshops at district and provincial conferences for other science teachers on the use of these types of learning activities so have become comfortable and experienced in their use.

Baird (1997) asserted that there are five key aspects of learning:-

1. Learning outcome is determined by decisions made by the learner
2. Inadequate learning is due to inadequate decision making

   Baird breaks this aspect down into seven negative habits - impulsive attention, superficial attention, inappropriate application, inadequate monitoring, premature closure, ineffective restructuring, and lack of reflective thinking.
3. Learners often are unaware of their learning problems. This lack of awareness generates poor learning.
4. It takes energy to learn with understanding or to unlearn a misconception.
5 Increased awareness of the nature and process of learning leads to improved attitudes and procedures. (pp. 8-10)

After more than thirty years of teaching science as well as textbook and resource guide writing and curriculum work I concur with Baird's synopsis.

Each of Baird's different aspects listed above relate to the three principle focuses of "metacognition - the knowledge, monitoring, and control of one's own learning" (p. 10). Gunstone (1994) gave a more expansive definition of metacognition:

> Metacognitive knowledge includes knowledge of the nature and processes of learning, of what are effective learning strategies and when to use these, and of personal learning characteristics. Inadequate metacognitive knowledge restricts the extent to which personal awareness and control are possible. Metacognitive awareness includes perceptions of the current teaching/learning activity, and of personal progress through the activity. Metacognitive control refers to the nature of the decisions made and actions taken by the learner during the activity. (p. 134)

Therefore if I wanted to change the direction of Geology 12 it was becoming clearer to me that I had to give the students some tools such as instruction on the nature and processes of learning, give them tools and time to reflect both on their prior knowledge and the development of their new knowledge, develop projects and activities that reflected prior learning in a curriculum that was more of a matrix than a disconnected linear path, develop projects and activities that encouraged problem solving with less focus on immediate right answers, and also encouraged interaction among all of us.

Change

Looking at the nature of change, I would suggest that the greatest struggle is with challenges to ones belief systems, and within that category some beliefs that primarily influence science teachers are those concerning the nature of science, learning, assessment and the absoluteness of the resources, all of which would be impacted if I intended to change my teaching practice with respect to Geology 12.

The literature on educational change indicates that high school teachers' frequently work in isolation, are not generally conversant with the professional literature pertaining to their field(s) of speciality and work in an institution where change is not an accepted part of the professional culture. At the secondary level, teacher preparation does little to change pre-formed attitudes and continues to reinforce the perpetuation of misconceptions. Teachers continue to be trained through the rigidity of disciplines - too many teachers are being produced with strengths in one area, with little or no background in other areas which they will inevitably have to teach. A typical science teacher will be expected to teach all the major areas of science in the junior high grades. Teachers find change very difficult to carry out, frequently limiting themselves to superficial or false change but not real change over time. A variety of reasons such as lack of administrative support, motivation and encouragement, or little peer mentoring, all tend to reinforce the status quo, (Fullan, 1991 and1993; Hargreaves, 1981).

However I soon realized that, if I were to challenge the status quo in terms of teaching a senior course in a somewhat unconventional manner, I had a great number of strengths. Prior to even considering teaching as a career I had earned an interdisciplinary engineering degree in metallurgy and when I started teaching did not identify myself as either a physicist or chemist. I had been teaching for almost thirty years, was a published author of textbooks and teacher's guides, had worked on a number of provincial assessment and curriculum projects, was very familiar with strategies that focussed on metacognitive learning and had developed significant hands-on activities in other grades.

Furthermore, in my new school I was my own little sub-department within science and during my first two years I was out in a portable, physically isolated from the rest of my science peers. For the first year I had the further advantage that in general I was an unknown quantity, and even by year two, most of my geology 12 students had had no experience of my approach to learning. A number of us in the school can teach physics, chemistry or biology at the senior levels and frequently discuss ideas and coordinate course content amongst each other, but I am the only Geology 12 and Earth Science 11 specialist and do not have to coordinate with anyone else in terms of my courses. The downside of that independence is that I am very much on my own, and at the same time potentially vulnerable to peer pressure to conform to more accepted practice.

I knew that I was embarking on major changes in my thinking that would be highly complex, challenging existing beliefs, skills and practices (Fullan, 1991 and 1993), both my own and my peers, and could rarely be effected by simple rules. I was already following Fullan's (1993) advice that ". . . teacher's must develop the habits and skills of continuous learning, always seeking new ideas inside and outside their own settings." (p. 81). I was experienced at researching both content and process in terms of improving my practice particularly towards improving student learning, and I was sure that these research skills would be put to good use. As Fullan (1991) further stated: "Change is a highly personal experience - each and every one of the teachers who will be affected by change must have the opportunity to work through this experience in a way that rewards at least equal the costs." (p. 127). Certainly by the end of the first year, the costs far exceeded the benefits but I could begin to see that over the next two years, barring any unforeseen catastrophe, that would turn around.

The Research Project

Fullan (1993) gave me further motivation when he suggested that as teachers "We should not think of vision as something only for leaders. . . . It arises by pushing ourselves to articulate what is important for us as educators. " (p. 13). In the fall of 1997, after I had unpacked my twelve boxes of gravel and plastic fossils, I only had a generalized view of my vision, but by Christmas of that year the course needs were clearly identified in terms of changes that focussed on metacognition and student learning. It was time to sort out some focus and direction as to what I wanted to accomplish, how I wanted to make change, and a time frame in which to complete substantive change.

Since I was essentially on my own I embarked on a qualitative individual action research approach, using as guidance the following thoughts from Quicke (1991), ". . . a view of research as a process whereby practitioners reflect on their practice with a view to improving that practice." (p. 76), McCutcheon and Jung (1990), ". . . by 'action research' . . . we mean inquiry teachers undertake to understand and improve their own practice." (p. 144), (Oberg and McCutcheon (1987) "(action research is) any systematic inquiry, large or small, conducted by professionals and focussing on some aspects of their practice in order to find out more about it, and eventually act in ways they see as better or more effective." (p. 148) , and Pine (1992), "Teacher (action) research is systematic, intentional inquiry by teachers about their own school and classroom work. They (teachers) see teacher (action) research as deliberate inquiry, not off the cuff reaction. It needs to be thought through systematically and pursued methodically, and reported in forms that are usable by other teachers and educators" (p. 657).

In my earlier life I had spent time in a research setting developing higher strength zinc alloys using a powder metallurgy approach in which all the variables could be individually controlled and isolated. During various education courses and workshops in which I had participated over the years I was constantly troubled by attempts to apply such an approach to education research in which there were little or no constants. Too much so-called research seemed to be focussed on a single facet of classroom learning or behaviours with no consideration of the many other variables involved, some of which the teacher could exert some control over but many of which were far beyond the influence of either the teacher or the school. As Baird, (1992) stated "Education is different from many other areas of study, particularly the sciences, in that there are few if any dependable, generalizable rules, theories, or practices. We must accept that, in the social sciences, pluralist, relativist explanations are more likely." Such an action research project as I envisioned would be the tool I needed to engage in pluralist research.

This was going to be a major reflective project that would significantly effect change in my personal practice compared to my earlier teaching. Having experienced, coped with and survived a number of significant changes in my personal life I was aware of Fullan's (1993) cautions that "Those skilled in change are appreciative of its semi-unpredictable and volatile character, and they are explicitly concerned with the pursuit of ideas and competencies for coping with and influencing more and more aspects of the process towards some desired set of ends." (p. 12). The changes that I was proposing to implement must not be seen as threatening to my peers, must not be seen as threatening to the administration, and most of all must not be seen by the students that they were being penalized by my alternate methods as I challenged their conservative notions of teaching and learning. Thus the overall thrust of the research was, within the constraints of the Geology 12 programme, to develop an interactive multilayered model for learning that encouraged more student independence, reflection and decision making in terms of their own learning. It became quickly apparent as the assessment of resources progressed that there would have to be a parallel geology research focus in terms of developing resources and in time it became difficult to separate one research focus from the other, they became very intertwined.

In order to construct an interactive, metacognitive programme for my grade 12's, I identified eight aspects of the vision that I had been developing. I had to realize that not only was I in a new school but I had new courses and that my energy had to be divided among all of them, I could not spend the next two to three years just on developing a Geology 12 programme. I had to be cognizant of time, energy, and life outside school. The eight aspects that I identified during those first few months, and apart from the first one they are in no particular order, were:

- Develop a more learner focussed topic matrix.

  This was a repackaging of the learning outcomes into a developmental matrix that both built on earlier learnings, allowed for reflection, and generally progressed from the concrete to the more abstract. This had to be the first task as this formed the foundation for the evolving classroom curriculum.
- Assess and inventory the available text resources

  Such an assessment would involve identifying areas that were problematic in the issued text in terms of being reader unfriendly, areas of content in which local, Canadian and world content needed to be inserted, and research suitable supplementary technical articles. The next task was to expand on my own core of writings to develop a comprehensive resource book.

- Assess and inventory physical resources.

  This involved identifying what I had, what I was missing that was essential to obtain as soon as possible, at least by the beginning of the second year, and further prioritizing for the future as I only had a small share of the science budget. This stage also involved developing inventory systems for the various resources.

- Develop storage systems for the samples.

  Some could just be labelled and stored in boxes. For other specimens, such as the larger minerals samples or small fossils that were more prone to theft, other systems had to be purchased, or designed and made, which took further from my time.

- Assess and inventory visual resources such as slides, videos and CD's.

  Once I had ascertained what was available this had to be followed again by a needs and source assessment.

- Introduce students to PEEL metacognitive strategies that focussed on multiple learning contexts.

  During that first year it did not take me long to find out that most of the students did not even know what a concept map was or that they could learn in more than one way.

- Introduce more decision making strategies for students.

  By grade 12 I had decided that my role was not to play mother and nag them every day about their work, but to give them some choices in how they organized their learning time.

- Start developing hands-on activities for each topic.

  This meant geology research and field work on my part over the next few years.

Apart from the initial development of the topic matrix, all of these aspects of my proposed course would entail research and change over time. as Rietchel (1996) stated "Although action research incorporates varying degrees of formality, by its nature, action research is an ongoing process of educational change." (p. 30). The hope was that by the end of year three that most of this would be in place, but it was recognized that for me the process would never end. I was too dedicated a teacher to suddenly stop being both a pedagogical researcher but also a science researcher. I initially developed in chart form a working plan for change over a three year time frame and the final form of this chart, expanded to four years, is illustrated in Appendix A. The arrows show where a base level would have been reached and there is just continuous monitoring and appropriate adjustments from then on. This working framework turned out to be surprisingly accurate and required no major changes of direction. The time I had spent working through both the theory and its implications for practice, coupled with my own extensive teaching experience meant that everything broadly evolved as I had planned. The role of the science researcher was less predictable and would depend on where I happened to be travelling and the resources I could locate.

One thing I did not plan on, but turned out to be mixed blessing in the end, was that at the end of the second year in the portable, the science department acquired a classroom in the main building just down the hall from the science labs. This had been intended to be a computer room and although not quite as large as a regular science lab in the school was almost twice as large as the portable, and significantly larger than the regular teaching classrooms and enabled me to keep my large student tables. So although the advantages were that I was in a bright and airy classroom and was close to my science peers in terms of professional communication around my junior courses, and more accessible in terms of the changes I was bringing to the teaching of a senior science course, the downside was that I had much less storage space than in the portable. The reader will see from the timeline chart that at the beginning of year three my storage systems moved from cardboard boxes to plastic storage bins with lids that were much easier to stack and lift. A friend made me a carved wooden sign "Ye Olde Rock Shoppe" that now hangs in the room and Geology 12 and Earth Science 11 now have much greater visibility in the school.

The next two chapters outline the development of these different aspects of developing my Geology 12 course over the last four years, as outlined in the timeline. They describe the development and implementation of the details and the evolution of a working relationship with my students as they struggled with some very profound ideas that challenged their beliefs about the nature of doing science and the nature of learning.

4. Developing a Class Curriculum

When I started at my new school I had already made the decision that I could not treat the grade 12's in the same way that I had taught my junior science classes for so long, and that I needed to consider significant changes to my practice if I was to be successful with the seniors, particularly as these students have an external final exam. I had identified a significant number of issues that would need to be addressed such as, long term rather than short term student learning, poor or lack of physical resources, reader unfriendly text, problems of the heavy reliance on a single text, lack of Canadian content, as much hands-on as I could create, an interactive more transactional classroom rather than a transmissive teaching approach, creating multiple contexts, and the difficulty that even grade 12 students have at being independent learners. I had this vision of developing a programme that would facilitate long term learning, the ability of the learners to take more responsibility for their learning, and to move my learners more in the direction of life-long learning. In this chapter I will discuss some of the issues raised in Chapter 3 and the methods and tools I developed to tackle them.

I had over time through a multiplicity of experiences as teacher and learner come to realize that there were a number of facets to developing a successful and independent learner. These can be listed as follows, and I have made no attempt to prioritize them. Learning:-

- takes time.
- means challenging previously held beliefs.
- requires that the content or concepts be intellectually processed by the learner.
- is a social activity.
- benefits by identifying and reprocessing mistakes.
- must be seen by the learner to be relevant and contextually situated.

- requires multiple exposures to concepts through a variety of contexts.
- requires that students take charge of and accept responsibility for their own learning.

Although similar lists can be found in a variety of education texts, and many of these can be further identified through the references previously cited, it would be dishonest for me to cite any specific source as most had already evolved in my thinking through many years of highly involved reflective practice, although the short article by Feik has had a significant impact on my teaching. This list is not intended to indicate all facets of learning but rather those facets with which I had some expertise individually and through which, in an integrated approach, I could hope to exert some influence during my day to day practice as a classroom teacher.

These facets of learning do not exist by themselves, they are all complexly interrelated within the context of a classroom in which active learning is regularly taking place. These interrelationships can be illustrated as a complex of overlapping circles, the inner circles shown below . But even this complex exists within an even larger structural matrix that includes an externally prescribed curriculum, an external exam and the individual school organization, issues over which the teacher has no control, middle circles. Overlaying all of these are socio-cultural issues over which I have no influence such as peer relationships, family relationships, parental education, social class, ethnicity, personal health, religion and access as shown in the outer circle. Compared to my previous role researching higher strength zinc alloys in which every separate variable could be individually controlled, all I could do, as Baird (1992) indicated, was to look at combinations of teacher behaviours and strategies which would interact to improve learning and build my class curriculum around those.

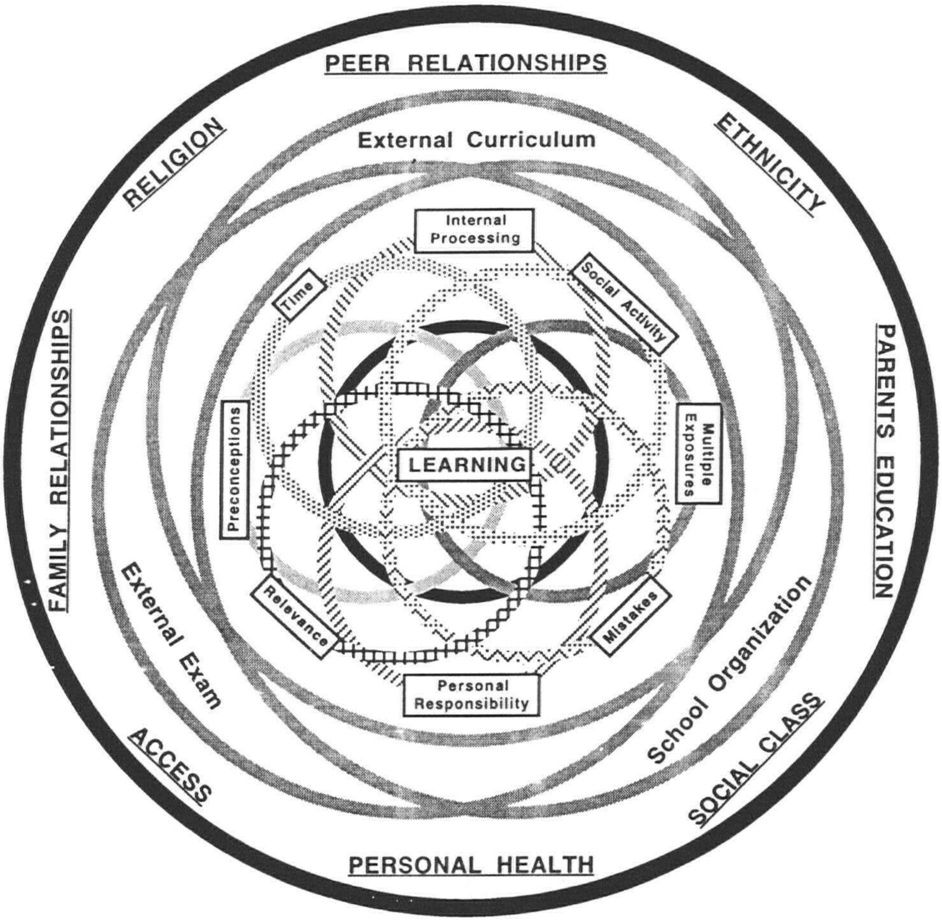

Figure 1. Interactions between some factors that influence student learning

There were many concerns but I had two tremendous advantages in that the changes I was considering were internally developed, not externally imposed and therefore had a far greater chance for success (Fullan 1991 and 1993, and Hargreaves 1994). The second advantage was that I am an older and very experienced educator who throughout my career have not been afraid to challenge the status quo, my science peers have generally been supportive of my efforts and I have been left alone by the administration. If I was a recent graduate with little experience behind me I would most likely have a harder time of breaking out of the mould.

Constructing the Class Curriculum

During the summer of 1997, prior to teaching Geology 12, I evaluated the Integrated Resource Package (IRP) in terms of both the content level and the potential sequencing of the learning, with the goal of setting up a course that constantly built on and reinforced prior learning, as well as ensuring that, for the most part, the necessary prior learning was in fact in place before a topic was started. At this point I was somewhat aware of the variability of my clientele in terms of existing knowledge. Keeping in mind the constraints of a final government exam I was mindful of the following thoughts from Doll (1989)

> We will envision curriculum, not as a linear trajectory nor as a course (with hurdles) to be run, but as a multifaceted matrix to be explored. In this matrix, places where one begins and ends are far less important than how one explores the myriad connections, logical and personal, inherent in the matrix. (p. 251)

With these requirements in mind I reordered the sequencing of the IRP topics and even some of the specific learning outcomes as shown in the table of Appendix B to work towards such a matrix within the framework of moving from the immediate and concrete to the more distant in both time and space. In this topic's chart, the numbers in the first column refer to the teaching sequence that I have developed, while the capital letters in the second column refer to the alphabetical order that is laid out in the IRP. In a few cases I also added extra learning outcomes to the topics to either bridge gaps to potential learning, or to extend their learning beyond the basic prescribed learning outcomes of the IRP to develop broader understanding.

In the Earth Materials Unit, Topics A - E stayed at the beginning to give a very strong grounding in the nature and identification of selected minerals and rocks, but the bulk of the Volcanism outcomes of Topic C, and Topic F, Mineral, Rock and Energy Resources, were taken out at this point in time. I felt that the Vulcanism fitted better with the Internal Structures and Processes Unit, and that the Mineral, Rock and Energy Resources, Topic F, learning outcomes would work better near the end as a separate unit. The

Surfaces Processes Unit, Topics P - S, then became the second unit for two main reasons. With such a varied clientele I felt that it would be easier for them to understand the concepts behind this Unit as this is dealing with relatively local and visual processes, and as well, a thorough understanding of sedimentation processes and structures would be a good grounding for relative dating techniques and fossilization processes, and for an understanding of structural geology.

Time and the Fossil Record, Topics G - J, became Unit 3, building on the minerals, rocks and sediment knowledge from the two earlier units. One cannot begin to understand such principles as original horizontality, uniformitarianism, and superposition if one does not have a knowledge and understanding the basic process of weathering, erosion and deposition. Unit 4 now becomes Internal Processes and Structures, with Vulcanism and a review of rock-forming minerals and igneous rocks being the first topic. Like Unit 3, Geologic Time, this unit also builds on earlier knowledge of minerals, rocks and sedimentation, particularly during the structural geology, seismology and plate tectonics topics. The plate tectonics topic now becomes the grand unifying theory that ties so much of the course together. Unit 5, Mineral, Rock and Energy Resources and Unit 6, Planetary Geology both act to further review and consolidate earlier knowledge, principles and processes. Two learning outcomes, "A 6 demonstrate an understanding that uniformtarianism is a fundamental principle of geology" and "A 7 demonstrate the ability to calculate the rate of geologic processes", have multiple applications and appear a number of times through the different topics.

After teaching this course four times I am very comfortable with this re-sequencing and the inter-connections that can be easily made. Some of the relationships between both the topics and the units are shown in Appendix C, a web or connections map of the class curriculum, which I give to the students at the beginning of the course. This is my interpretation of a matrix with myriad connections for this particular course, even though only the major connections can be illustrated on a single sheet of paper. This web map is intended to illustrate to the students that the course is not one of segregated topics–learn a topic and then forget it until the exam approaches–but rather a well co-ordinated approach to learning that acknowledges that learning requires multiple exposures to a concept in different contexts (Doll, 1989; Feik, 1991). This web or map is put on the overhead at the beginning and end of each unit to review where we have come from and give a context to where we are going over the rest of the semester. By the end of the second year teaching within this topic framework I recognized that it was so successful in practice through the constant making of connections and re-connections that I have not changed it since then as shown in Appendix A, the initial time frame for change.

Beginning to Take Control

At the beginning of the course I hand out to each student a chart listing the topics in order together with spaces for them to list the date each topic was assigned, the date due, and the date handed in if applicable, Appendix D. This form of self monitoring is frequently new to many of the students and is one of my initial steps at helping them develop into more independent learners. This is the first stage for many of them at taking charge of their own learning.

Prior to each topic I set the direction by listing the prescribed outcomes for that topic according to the IRP with any supplemental outcomes I have added at the end. The format for each is similar, starting with the learning outcomes, followed by a listing of the principle resources the students will be using for that topic, and concluding with a listing of web-sites that could be useful to furthering knowledge of that topic. The web listings are checked during the couple of weeks prior to starting each course to confirm the validity of the addresses, Appendix E. This type of pre-organization for the students has been new to both my students and my peers.

I have included in Appendix E the learning outcomes and resources pages for the three topics on which I will be focussing during the rest of this thesis:- Topic 3 - Igneous Rocks, Topic 12 - Volcanoes In

Action, and Topic 23 - Mineral, Rock and Energy Resources, each of which demonstrates a different dimension of the programme I have developed. During Topic 3 the students are expected to do a great deal of interactive hands-on work with large working samples. The resource list also introduces them to surface geology maps of the Lower Mainland. There is only one web-site listed as most of the others relating to this topic are not as useful or somewhat commercial. Topic 12 on the other hand is illustrating the use of semi-technical literature as supplementary resource material, in this case literature focussing on the volcanoes of south-west British Columbia. By semi-technical, I consider such journals as Geos, Scientific American, The New Scientist and Geoscience Canada, examples of writing for the literate individual but not necessarily the detailed specialist. For the students this is a new concept–that all knowledge is not confined to prescribed textbooks, and again I am the only teacher as far as I am aware in the school using such journals as part of their learning programme. Topic 23 on the other hand focuses on resources and their extraction, and in this example the comprehensive web-site listings detail the mining industry's viewpoint, arguments from environmental groups and a selection that looks at mining in Canada from a historical perspective and the dangers involved.

Assessing Prior Knowledge

It is important to me that, if we as educators are focussing on student learning, by grade 12 students should be able to assess their prior knowledge of a list of learning outcomes and be better able to monitor their learning. From this, students will hopefully be able to also identify and challenge some of the misconceptions in which they believe as they proceed through their learning. In a course that terminates with a significant external exam, time is an important commodity; such an assessment of prior learning must be quick and easy for the students to work through.

By the end of my first year I had developed a simple chart for assessing prior learning, a final form of which for Topic 3 as an example is shown in Appendix F. This is a chart that has five columns, a wide one on the left in which the learning outcomes for the topic are listed, and four smaller ones for checking on the right. Of the smaller columns, the first one is headed "Must Learn or Practice" and is usually checked off by students who have not taken Earth Science 11 as their prerequisite. Those that have passed Earth Science 11 usually check of the second box, "Not Sure", indicating that they know something about the topic at least. The third column is intended to be finally checked off at the end of the topic and before the final assessment as a self check that all the necessary learning has taken place. At the end of the third year I added the fourth column, "Relearn", by which students can reflect on and evaluate continuing weaknesses in knowledge and understanding after having completed the formal assessment for that topic. I monitor completion of this chart for about the first six topics by which time those who find it a useful tool have fallen into the habit of completing the chart. Those who are not interested in monitoring their learning or taking advantage of having their weaknesses identified have, as Baird (1997) asserted, made a personal learning choice, although I do remind the class periodically of the potential usefulness of this or similar charts.

Unfriendly College Texts

It was established earlier that the course textbook I am using by Thompson, Turk and Levin, (1995) is a traditional college level text that is strongly focussed on the United States with little or no Canadian or World content, is somewhat reader unfriendly, and is very traditional in design by not making use of a number of strategies that facilitate reader learning. I was fortunate in that I had developed a resource book for elementary teachers in my district, Williams (1995), that was designed to explain in straight forward terms the science concepts behind the various components of the then new elementary science curriculum. This book was more than 600 pages long, with over 1000 hand drawn graphics that was presented as a series of interlocking modules, and fortunately two of those modules dealt with basic Earth Science concepts.

Using these two modules as the core I expanded the content to more closely meet the needs of the Geology 12 learning outcomes to create a Geology 12 Resource and Activity Guide that currently extends to over 230 pages of my own writing and more than 160 black and white line drawings. The guide also contains excerpts from a variety of other print sources as well as copies of the semi-technical articles mentioned earlier. The table of contents for this guide is reproduced in Appendix G, while Appendix H lists the principle supplementary articles. All the way through the last four years this has clearly been a double research project and in terms of developing the Geology 12 Resource and Activity Guide the science research has been very extensive as indicated by Appendix I that lists the complete text bibliography for the guide. A compilation of the internet sites listed on each of the topic overview pages takes a further six pages, but has not been included.

The motivation to spend the hundreds of hours of research, writing and drawing, as well as the personal costs of travel and purchases, to develop this resource and activity guide was seven-fold:-

- To create a supplementary resource that focussed on British Columbian, Canadian and World geological examples to counter the dominant United States slant of the text, to supply a more local context, and model the concepts that teacher's can be authors and researchers.
- In topic areas that created the greatest difficulty, create readings that were more learner friendly. Topic areas that are covered adequately in the text have not been rewritten.
- To supply appropriate readings from the literature to supplement their learning, supply a list of quality internet sites, and to model that there are other resources beside a textbook.
- To develop the hands-on activities that I wanted to be the basis of as much of the learning as possible. I strongly believe that geology is a tactile learning experience. To paraphrase Feik, one cannot learn about rocks by looking at pictures in a book, videos, or the internet, one has to handle and work with the different minerals and rocks.
- To develop the habit of thinking in terms of multiple resources. It has been my experience, as clearly identified in the literature, that there is far too much reliance on a prescribed text. We as

educators must model the use of other resources if we expect students to expand their thinking.

- To correctly model how to use and cite other's work, as every supplementary article or graphic is correctly cited. Even this concept is new to many of my peers unfortunately.
- To model that I enjoy teaching and learning and doing the research needed to develop such a resource and keep it and the course up to date. If I can be seen to be a lifelong learner then it becomes easier to challenge the students to aim in that direction,

The motivating factors can be divided into two categories. The first and more obvious category is that of facilitating student learning. The second, but more subtle category is one of modeling desired different behaviours both to my students but also to my peers. This aspect of modelling seems to be one that we as educators generally ignore, yet through my many years of working in a variety of educational contexts is one that is very important if we believe that change can be achieved.

During the first two years I was developing my Geology 12 Resource and Activity Guide, the activities were integrated at the end of each text topic. As my school and personal resources increased the activities began to increase, both in extent as well as in complexity. This meant that any changes to the activities resulted in reprinting the whole guide each year at considerable time, mine, and expense, the school. During the second year in particular some articles and activities were rewritten two or three times as problems and issues surfaced. The students became quite used to me giving out a topic package one day only to replace it one or two days later. If some aspect of the classwork was not working as I had intended I had to assess, evaluate, redesign and rewrite quickly while the problems were still testable, not wait until the following year when I next taught the course.

By the third year the bulk of the text was substantially in place and that year I separated out the activities from the reading component. The supplementary text material was printed out on white paper and to be kept in a separate three ring binder much like any other print resource with the intent of collecting it back in at the end of the course to be used again. The Activities and any worksheets were printed out in a pale sand colour and were to be kept by the students in their daily work journal. This worked well and means that each year I only have to reprint the coloured section. If I do make major changes to a text topic, it is a relatively simple and economical process to just reprint and exchange that topic, but for the most part I expect updates to come in the form of supplements for the next few years rather than a wholesale rewriting of large sections. After four years of working with this approach I know that it works.

Evaluation of any new project or approach to learning is very difficult in education as there are so many inherent variables that cannot be controlled. In the case of this resource book the evaluation has been in seeing how much the students enjoy working with it. At the end of the course when they are expected to turn the resource guide back in, to save my time and the school money in theory, at the end of the third year about 50% of the students asked if they could keep it. At the end of the last school year, my fourth year teaching Geology 12, more than 75% wanted to hold on to them as they expected them to be useful during their first year of post secondary education. Each year I have been getting a higher percentage of students taking the course who are intending to continue their studies.

Expanding Resources

The title of this thesis, Twelve Boxes of Gravel and Plastic Fossils, summed up both the type and limitations of the school resources but also a cry of despair at the task ahead of me. The core of the collection were a number of Collectors Sets of rock chips and of mineral chips from the Geological Survey of Canada that have traditionally been considered to be the essential resource for teaching about minerals and rocks, and in fact were listed as such in the previous Geology 12 Curriculum. Fragments of other rock and mineral sets were also present. I have previously described the early weekends sorting through the mess and finally producing individually numbered and or labelled resealable plastic bags for the different minerals and rocks in these mixtures of sets. I also had to then develop a numbering and inventory system so that I could track them.

Although I had used these small sets as a primary teaching/learning aid in my Junior High classes I had already realized that these tiny samples, averaging 2 - 3 cm per side, were far to small to use if I wanted students to critically learn about the properties of the different minerals and rocks. I had previously started to collect larger hand-size rock samples, 8 - 10 cm per side or larger, and the best of these I retrieved from my previous school. That first year I was pretty much stuck with what I had, with no choice but to use these gravel sized chips.

I believe passionately that geology has to be as much hands-on as I can make, and part of that means working with large samples not pieces of gravel. During the last three years I have extended my collection of rocks to over one hundred and fifty. Working with real rocks is working with primary source data - one can directly apply one's knowledge of properties to infer an identification and provide real evidence for your decision. Looking at pictures in a book means using secondary sources at best, often with no indication of context, texture or size and of only seeing one example of each type illustrated. It is very easy for students to develop fundamental misconceptions such as that all granites are essentially white, or all sandstones are basically sand-coloured, classical examples of generalization from the particular. With a large collection I can have them compare five or six granite or sandstone samples to better understand the variations in composition and texture that still enable these samples to be granite or sandstone. I can have seven or eight samples of basalt exhibiting a wide variety of textures, rather than the one small chip and the one textbook picture with no scale attached to it.

However this does mean that I have to do a great deal of research as to where different rocks can be found as it is not very practical to just go wandering off into the bush by oneself in the hope of finding something. That has also meant that I need to build up a personal library of field guides, frequently buying one of an area even if I know that I will not be visiting that area for some time. Such books come into new or second-hand book stores in only ones or twos and so I have to grab them when I can. Before travelling anywhere I have to do not just the travel research but also the geological research and fortunately I enjoy that aspect of my teaching and learning. Since it is not so easy to find good mineral specimens in the field unless one has a contact, during the last two years I have started to purchase hand size mineral samples for the school from some of the supply companies and also local rock and gem stores, and have currently acquired about 60% of my needs. Buying locally at least gives me a chance to examine the specimens rather than buying them blind from a catalogue. Unfortunately the illustrations of minerals shown in texts or on some of the more common internet sites show museum quality specimens, and do not mean much to the students when they compare the pictures to their small samples, even the larger hand-size samples. This is an even bigger problem when museum specimens are illustrated in the final exam, a far cry from even good mine samples.

The basic specimens for rock and mineral identification are only part of the lab work. I have built up collections of rocks exhibiting different types of physical and chemical weathering, or combination effects and collections of different types of volcanic products for the students to use. Frequently such specimens are not commercially available. I am also building up a "museum" set of prime specimens that are on permanent display and I can just go over to the counter to pick up a couple of samples as necessary to illustrate a particular concept. Although it is not one of my focus topics, I have included the specimen list for Topic 6a Weathering, Appendix J, to give a sense of the types of non-commercial specimens that can be used for hands-on work. I should point out that in specimens such as these there may not necessarily be absolute right answers, rather it is more of a best answer based on the evidence. The evidence for the decision is of key importance in an assignment such as this. The Topic 6a list illustrates another difficulty of running a hands-on focus when teaching Geology 12 in that the list is written so that a replacement teacher can have a sense of the nature of the samples as there are very few Teacher's-on-Call who have a geology background.

Field Work

My collecting kit lives in my car, and anytime I travel I also ensure that I have two cameras, one for prints and one for slides. At the end of my first year of Geology 12 I had the opportunity to visit Victoria, Australia to stay with some friends from the British Columbia interior who were exchange teaching east of Melbourne and I came back with six kilograms of rocks in my luggage. Whenever I travel, I try as much as possible to collect extra samples to build up a set for my current school for when I retire, a set for my daughter who has recently started teaching Earth Science 11 in a different district, and a set for a younger friend who has recently started teaching Earth Science 11 and Geology 12 in a new school that has little or no resources. However if one is flying collecting multiple specimens is not always possible. The only criteria I impose on these other teachers are that if they ever find anything interesting to bring me back a sample to add to my collection. Former students and current teachers are now starting to bring me in specimens and it is becoming interesting each September to see what awaits me.

As well as rocks I needed fossils and for the first year I used my own personal samples. For the second year I was able to purchase a number of samples to start a core collection for the school. I have also donated some of my specimens to the school to both fill in gaps but to also supply local context. Other samples I deliberately seek out, particularly from friends, are sand samples and I have samples from every continent except Antarctica. A film canister of sand can last a long time and be shared with a number of other teachers. A small sample of the sand is sealed into labelled deep well slides for use under a dissecting microscope, and can be used to illustrate different degrees of mineral breakdown, the effects of different types of weathering for example, or for a problem solving activity. And then there are the serendipitous samples such as the glacial striations or the ripple marks that one comes across unexpectedly but after which I come home cold and wet from a day of rain but grinning from ear to ear. In all cases in which I have collected specimens whether they be rocks, minerals, fossils, or anything else that I can use, I have a story, a context, to go along with that sample. It is something that is now taken out of the abstract, and acquires some meaning in time and place. I will discuss the use of stories in the next chapter, as they are a powerful contextual tool.

I have found over the years that I personally do not use commercial videos very much in my geology teaching. There are three main problems that concern me - the amount of material that is covered, the impersonality or blandness of the narrator, and the mistakes frequently of generalizing from the particular as mentioned in the section on textbooks. It takes a great deal of processing time and multiple showings to begin to process a typical video if one is truly concerned with students' learning, rather than twenty minutes for the teacher to do something else. I still, after all my years of teaching, keep coming back to using low technology 35 mm slides. If I, as the teacher, have taken the slides I am now sharing that experience with my students. I am modelling not just the concept of field work, but that I am a researcher photographer truly interested in this material and that I enjoy what I teach. Each slide, like the hard samples that have been personally collected has a contextual story. The first time a student new to me asks if I took the slides and I say yes, then I know the class is hooked, but I have to always explain the slide's origins if it is not one of mine, subtly modelling the concept of intellectual property.

Apart from developing my field knowledge the geology research focussed on building a slide collection and a collection of hand-sized rock samples for a variety of classroom uses, not just identification. The initial focus was on developing a complete set of large samples of the rocks prescribed in the Provincial Learning Outcomes for Geology 12. The second focus was on collecting rocks that could be used as examples of processes or products in specific topics such as weathering and volcanoes. The following discussions describe collection and photography trips specifically carried out since I started teaching Geology 12 four years ago. As an indication of the success of doing the initial research followed by the field work, collection and photography, I now have 110 large rocks in my basic collection compared to about 25 at the beginning, plus those samples needed for two sets of hands-on activities, Weathering with 24 samples divided into 15 Stations, and Volcanoes with 42 samples divided into 14 Stations. There are a number of other samples illustrating different processes such as glacial scratching and ripple marks. The slide collection has increased from about 1100 slides to almost 3000, together with a number of prints that have been turned into wide view composite pictures. Friends have helped me collect about 80+ sand samples from around the world that are mounted in deep well slides for microscope viewing.

As well as using text and Internet sources to develop a trip plan, I soon discovered that a wealth of information could be learned from the local people that in all cases extended my resource collections beyond those described in print. I also learned al great deal about the design and usefulness of field trip guides, particularly as most of the time I was travelling by myself. As most guides do not open flat or stay open flat when laying on the passenger seat, a system of wide clips and elastic bands was frequently used to keep pages open and in place. A calculator was also frequently necessary as trip distances were usually only given in one direction.

Central Oregon

Principle reference:- Roadside Geology of Oregon by Alt, D. D. & Hyndman, D. W. (1978)

This trip followed Interstate 5 through Washington State, then using Oregon Highway 12 to cross the southern flanks of Mount Hood to Oregon 97, then south to Klamath Falls and Medicine Lake shield volcano in California. As this was done during Spring Break I was limited to what I cold access from the main roads as the side roads were still snowbound and generally did not open until late May.

Specimens: Bend area - 700 000 year old Tumalo pumice, cinders from different cones, weathered columnar basalt.

Southern section of Highway 97 - various samples of Mazama pumice, Aa lavas.

Photography: Oregon flood basalts, most of the Oregon volcanoes, and some lava flows. At Medicine Lake, lava tubes, columnar lava, aa lava and pahoehoe lava. This included one spectacular site at which all three types of lava flows were superimposed on top of each other.

Victoria, Australia

Principle reference:- Volcanoes in Victoria by Birch, W. D. (1994)

This trip was based at Drouin, 93 km east of Melbourne. Local knowledge was important here.

An extended car trip took me along the southern coast road to the border with South Australia returning to Drouin through the Grampian thrust fault mountains in southern interior of the state. Again local knowledge tuned out to be extremely important. As I was flying, I was limited in actual sample collection and focussed my attentions on materials that I could not easily obtain her in western North America

Specimens: Mortlake area - cinders, volcanic bombs and tuff. Grampians - old red sandstone

Photography: Droiun area - Mass wasting, folding and faulting

Coast Road - Coastal erosion, cinder cones, lava tubes, lava flows

Grampians - thrust fault mountains, sandstone formations, mud cracks in shale

North Island, New Zealand

Principle reference:- Discover New Zealand: Volcanic Places by Ell, G. (1986).

Geyserland: A Guide to the Volcanoes & Geothermal Areas of Rotorua by Houghton, B. F. (1982).

For this trip I was based at Rotorua in the centre of the North Island. Local knowledge was important here. Since this was on the return home from Australia, I was limited in the rock samples I could bring back.

Specimens: Taupo pumice, sinter

Photography: dome and composite volcanoes, extensive geothermal activity, eruption damage.

Southern Canadian Rockies

Principle references:- Handbook of the Canadian Rockies by Gadd, B. (1995).

Geology along Going-to-the-Sun Road, Glacier National Park, Montana by Raup, O. B., Earhart, R. L., Whipple, J. W., and Carrara, P. E. (1983).

Excursion A03 - C03 Geology of the Southern Canadian Cordillera (Glass, D., J. Ed) by Monger, J. W. H. & Preto, V. A. (1972).

The geology section of this trip started at the west end of the highway through Glacier National Park, Montana, returning to Canada near Pincher Creek, Alberta, following Highway 3 west to Castlegar. The Going-to-the-Sun Guide through Glacier National Park was extremely well laid out with distances measured from both directions and I was able to locate all the stopping points listed and described in the guide.

The Geology of the Southern Canadian Cordillera was based on a guided trip for participants attending an International Geological Congress Symposium in 1972. It was hard at first plugging into this trip as I joined the route part way through. This trip also entailed highly specialized stops on private property that were no longer accessible and made the task of following the road log very difficult. Along the Salmo-Creston section the road had been widened and the indicated stopping points along that section of highway could not be safely identified and had to be left out. For sample collecting I was able to identify and stop at the following locations from this guide 4.2, 4.3, 4.4, 5.1, 5.5, 6.1, 6.4, and 6.5. Other stops were primarily of photographic interest.

Specimens: Pincher Creek - clear and fossil sandstone from a local quarry

Crowsnest area - coal, coke, limestone

Highway 3, Crowsnest to Castlegar -greywacke, siltstone, mudstone, fine sandstone, green sandstone, mica schist, and phyllite

New Denver area - gneiss, slate, and quartzite

Photography: Glacier National Park - sedimentary rocks, intrusions, folding, faulting, glaciation features

Pincher Creek to Crowsnest - sandstone, plain and with ripple marks, old coal mines, Frank Slide, thrust fault mountains, and erosion.

Crowsnest to Castlegar - thrust fault mountains, Rocky Mountain Trench, tilted sedimentary and metamorphic strata, old mine remains.

New Denver area - metamorphic strata, Sandon

Central Canadian Rockies

Principle references:- Handbook of the Canadian Rockies by Gadd, B. (1995).

How Old is that Mountain? A Visitors Guide to the Geology of Banff and Yoho

National Parks by Yorath, C. J. (1997)

Of Rocks, Mountains & Jasper by Yorath, C. J. and Gadd, B. (1995)

Yoho National Park, Cameron,K. and Chevalier, L. (1997)

Since this was totally inside the two big National parks of the Rockies I did not collect any samples and this was primarily a quick photographic excursion having to be cut short as the friend who was with me became sick.

Photography: Thrust fault mountains, synclines, anticlines, glacial erosion, Athabasca glacier, river erosion and deposition

South-west British Columbia and North-west Washington State

Principle reference:- Fossils from the Harrison Lake Area, British Columbia in Bulletin No. 63 Contributions to Canadian Paleontology, Crickmay, C. H. (1930)

West Coast Fossils, Ludvigsen, R. & Beard, G. (1994).

The Geology of Southern Vancouver Island: A field Guide, Yorath, C. J. & Nasmith, H. (1995).

Excursion A02 Quaternary Geology of the Southern Canadian Cordillera (Glass, D., J. Ed), Fulton, R. J. & Halstead, E. C. (1972)

Excursion A03 - C03 Geology of the Southern Canadian Cordillera (Glass, D., J. Ed), Monger, J. W. H. & Preto, V. A. (1972)

Excursion A05 - C05 Geology of the Vancouver area of British Columbia (Glass, D., J. Ed), Mathews, W. H. (1972)

Memoir 243 Geology and Mineral Deposits of the Princeton Map-area, British Columbia, Rice, H. M. A. (1960)

Memoir 335 Vancouver North, Coquitlam, and Pitt Lake Map-areas, British Columbia, Roddick, J. A. (1979).

Geology and Geologic Hazards of the Vancouver Region, Southwestern British Columbia. Geological Survey of Canada Bulletin 481, Monger, J. W. H. (ed.)

(1994)

Garibaldi Geology, Mathews, W. H. (1975)

Geology of the North Cascades, Tabor, R. & Haugerud, R. (1999)

Vancouver Geology, Armstrong, J. E. (1990).

These resources were used for day or weekend trips out of my home in Maple Ridge as well as identification of the various fossil specimens collected. As with some of the older guides used in other locations there were some problems with sites not being located as roadwork had changed the location distances, or it wsa not safe to pull off the road.

Specimens: sedimentary and volcanic rocks, various weathered samples, plant fossils, marine fossils such as ammonites, belemnites, gastropods, and pelycepods, examples of ancient environments - ripple marks and raindrops in mudstones, effects of longshore transport.

Photography: fossil strata, intrusions, anticlines, exfoliation, glaciers and glacial effects, lava flows, columnar jointing, weathering effects

To go fossil collecting is another example of the geology educator, not as a teacher, but as a science researcher, as on my return the samples have to be cleaned, labelled, identified and catalogued and again the field guides, local geological bulletins from the Geological Survey, or other technical reports listed above become important research tools. For example, to identify some pelycepod fossils from the east side of Harrison Lake, BC, I had to turn to an edition of "Contributions to Canadian Paleontology" dating from 1930, and for identifying insects from the Princeton, BC, area go back even further to a 1910 copy of the same journal.

When I started Geology 12 four years ago I had about 1000 slides related to geology. Now, after trips through British Columbia, down through the Cascade mountains of the western United States, to southern Florida, through the Rockies and to Australia and New Zealand, the geology collection has increased to almost 3000. Like the rocks, fossils and sands, these require careful cataloguing and organization and the task is manageable using a basic computer data base. Such data bases were very time consuming to set up initially, but now it is just a case of updating the new information. The slides are stored by topic and sub-topic in transparent sleeves in sturdy three ring binders. For example, I have one binder just for volcano related slides broken down into assorted subtopics such as type of volcano, lavas, and intrusive effects and at the front of each section is a print-out from the data base of every slide, by code number and page, in that section. Setting up a good inventory management and retrieval system is necessary in this type of course if one intends to be an active hands-on educator. If a Teacher-on-Call is expected to show slides during my absence I can always printout the pertinent data for his/her use.

I mentioned earlier that I take both a slide camera and a print camera. This is somewhat of an insurance policy if something happens to one of the films, for example I lost a whole role of film from New Zealand showing geysers when the film was not wound on properly. I had tried to change the film in pouring rain with only my body for shelter and was not careful enough winding on and checking that the film had caught on the take-up spool. Although making slides from prints is more expensive than the reverse process it is still cheaper than revisiting New Zealand for example. However prints can be used for making panoramas of large vistas such as open pit mines or folds and faults, for illustrative purposes to place samples in context, but also for problem solving or assessment activities. I always have to keep in the forefront of my thinking that if I am truly interested in long-term learning that, even though the single most important assessment is the external written exam, there are many other assessment tools that encourage higher level thinking skills.

Although I had repackaged the curriculum into a more learner friendly sequence, had identified many shortcomings in the assigned texts and created solutions to broaden the learning context, had developed a simple tool for the students to asses their prior knowledge and monitor their own learning, had built up a large collection of resources and their necessary management systems, these were still just my support systems. I still needed to develop a classroom learning model that created the time for me to do the hands-on activities in which I so strongly believed, create opportunities for Feik's multiple contexts and processings, further develop Doll's curriculum matrix, and give back to the students much of the responsibility for their own learning, and still remain focussed on the Provincial exam. This is the substance of the next chapter.

5. Developing Multiple Contexts

In the previous chapter I discussed the development of the some of the tools and support systems that I needed, such as packaging the curriculum into a more learner friendly sequence by moving from the more concrete to the more abstract, creating more reader friendly text with a much broader learning context, developing a student self assessment and monitoring tool, and how I had built up a large collection of resources and their necessary management systems. In this chapter I will discuss the development of a classroom learning model that created the time for me to do the hands-on activities in which I so strongly believed, created opportunities for Feik's multiple contexts and processings, further developed Doll's curriculum matrix, and gave back to the students much of the responsibility for their own learning.

A typical semester has about 82 classes, most averaging 75 minutes, and during that time I am expected to provide superior learning opportunities for a Geology 12 class of mixed intake skills as we work through twenty four inter-related topics. This averages out to three and a half classes per topic, not counting time for assessment. Some topics are short and only require one or one and a half classes, while others take up to seven. We do not have much time to waste and I have become very critical of how to best use class time for effective learning. For each topic I separate out with the students aspects of the learning that have to be done at school, such as access to samples or visual materials, from those learning tasks that can be done at home or at least away from the classroom.

Furthermore, I keep a running diary on a bulletin board for the students as we work through each topic listing what parts of the learning I am responsible for organizing and what parts are up to them, when the completed topic is due and what will be happening in terms of assessment. The diary outlines a schedule that, if the students keep to, will enable them to complete the assignment comfortably provided that they are productive during their in-class time. Other than that they are on their own. If they have not already copied down the schedule for each day they can check on the bulletin board to see what is happening and what might be due, and where they should be in the topic. If they miss class without a good reason that is their problem, the slides or video will be missed, and the bins of samples may have been put away. If they do not want to do part of their homework for one or two evenings, they are responsible for completing the work by the due date. The model is based on the assumption that if the "job", in other words the processing, is done properly then learning will inevitably follow, and the final exam no longer becomes that large noose around our necks.

Within the first few days of starting any course I, as the teacher, am expected to give the students a handout that provides an outline of the course, my expectations in terms of attendance and completion of work, assessment procedures, necessary tools and equipment and tutorial times and places for example. The first four paragraphs of my Geology 12 Syllabus outlines my philosophy around learning as applied to this particular class.

> GEOLOGY 12 is a government examinable academic science course. It provides an excellent opportunity for maturing learners to apply general science skills to a specialized field of study. This curriculum is based on the prescribed learning outcomes of the *GEOLOGY 12 Integrated Resource Package* (British Columbia Ministry of Education 1996. pp A13 - A23.) The course is designed to allow learners to develop an understanding of the Earth and the changes it undergoes. This study provides the opportunity for learners to develop their ability to take their places in post-secondary learning environments.
>
> Learning is the ability to apply one's knowledge and skills to new situations, not to just regurgitate memorized, often irrelevant, facts. Learners need to both process and practice skills and concepts. One quick read works only for exceptional students.. "Passive learning does not

work. Learning has to be as active as possible—learning and understanding does (sic) not occur until the learner has internalized and taken ownership of the concepts," (Feik, Aaron. Learning concepts. *Washington Science Teachers' Journal.* September 1991). You learn to ride a bike by riding it, rather than by reading about it, painting it, memorizing the parts, or finding out how many types of bikes there are. Similarly you learn about minerals and rocks by working with them, more than by looking at pictures or reading stories about them.

Learning demands a regular and steady approach to assigned tasks. You are expected to take charge of your own learning. Although you will review all concepts and questions in class, detailed answers to the review questions will be posted on the bulletin board until the next class for you to check your answers. For clarification, or if you are legitimately absent or late, you will be able to check your answers from the master binder or arrange an appointment for private discussion. It is your job to check and correct your completed work.

Your teacher, parents/guardians or friends cannot do your learning for you. Copying from your friends does not involve any processing on your part. Therefore, although assignments may be completed on time, you will not achieve the learning objectives if you have not done the processing. **In other words you will be expected to "do the job".** Arriving late, skipping out, or having a temper tantrum because you think this approach "is stupid", are inappropriate behaviours in this academic science course. **Only you can do the processing that is so necessary to your learning.** (Williams, 2001a)

This outlines for the students at the very beginning of the course that this is an academic science course focussed on higher level learning, and their responsibilities for their own learning.

Students coming into my Geology 12 class have been well trained in their earlier years to answer questions. The first and generally only task that they want to do is read what is assigned, preferably from one book only, and answer any questions. Every year near the beginning of the course I have at least one conversation such as the following.

> Student "Ms. Williams, what do I do now? I have finished all my work. I have done the reading and answered the questions at the end of the assignment."
>
> Ms. WIlliams "I do not remember assigning any question yesterday.That is not what it says on the bulletin board. Did you do the critical reading and identification of key words/phrases so that you could start expanding those into your own full study notes today?"
>
> Student "No, but we have to do the questions anyway. There were a couple I could not answer, can you give me the answers then I will be finished."
>
> Ms. Williams "How about putting the questions aside until we are ready for them, and getting on with the work I assigned? If you are not sure what to do, discuss it with your partner first, before coming to ask me. You are already behind schedule."

The general attitude of the students at the beginning of the first two years until I became better known was illustrated by a quote from McNiff "Why can we not have one textbook and use it for all our work. You could tell us what chapters to look up and answer questions like in our other lessons" (p. 108). I have found over the four years that it now takes between three and four assignments before the students start to independently work on the process that I am about to outline. It took the students somewhat longer than that for the first two years.

The Multi-Stage Learning Model

The learning model I have developed has eight stages, shown schematically first followed by a brief outline of the separate stages.

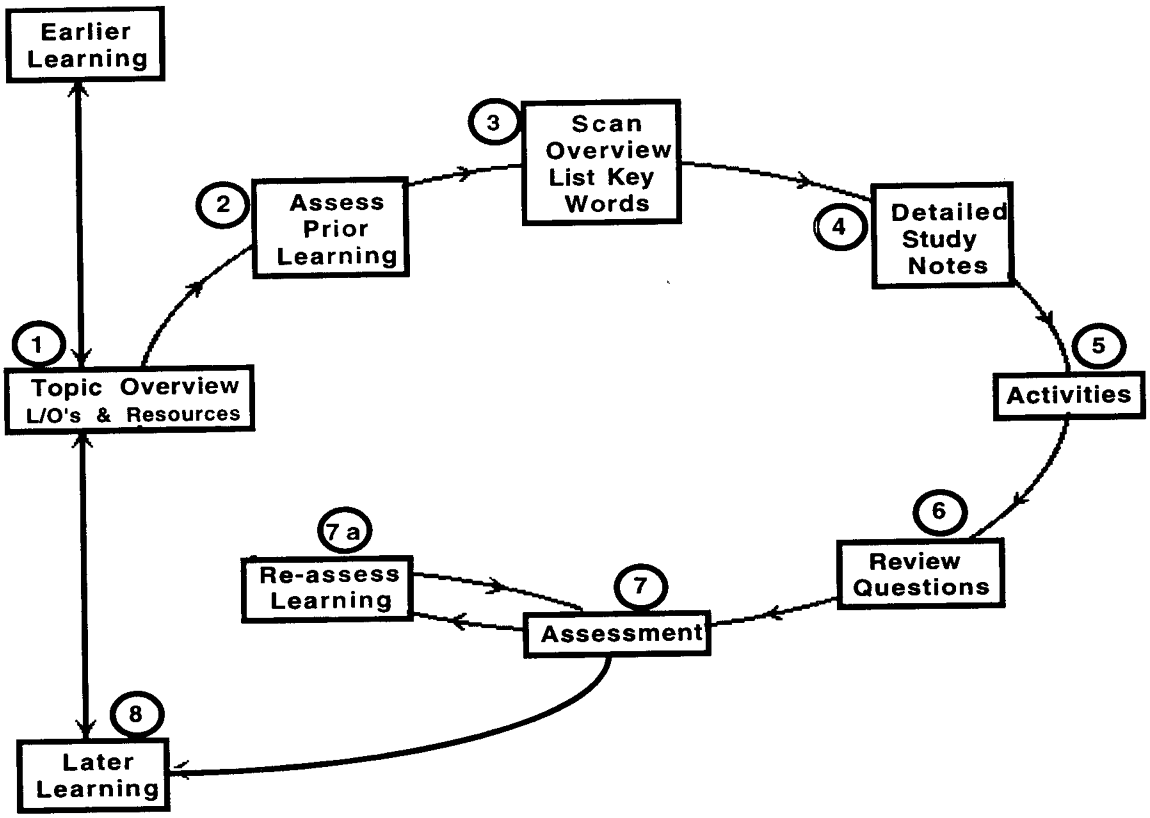

Figure 2. Schematic of the Multi-stage Learning Model

1. The teacher introduces the new topic with a brief discussion indicating how this new topic relates to previous work, and possibly later work and by referring to an overview page that outlines the specific learning outcomes and the principal resources that will be used, Appendices C and E

2. Students complete a record chart based on the learning outcomes for a self assessment of their current knowledge, Appendix F.

3. Students scan read the various print resources and develop a list of key words and key concepts within those resources, these key words to be merged into a coherent learning sequence. A sample Key Word list for Topic 3 is shown in Appendix K.

4. After review of the key words and concepts in class the students construct their own study notes from the various resources, keeping within approximate length guidelines supplied by

the teacher.

5. Students participate in a variety of hands on activities to practice, reinforce, or add to their print learning.
6. Students complete a set of review questions based on the learning outcomes.
7. Students undergo some level of assessment of their learning, and then do a self check as to their learning effectiveness, 7a, with the chance for re-assessment later.
8. Move to the next topic as outlined in stage 1.

The students are introduced to the multi-stage learning model with the basic student outline in their Geology 12 Syllabus handout that is given to them on the first class of the course. The following student instructions are taken from this syllabus and reflect stages 2 to 6 in the above sequence.

For the majority of assignments in this course you will be expected to follow these general steps:

1. Skim read all the reference materials in the assignment. For each of the readings develop a list of Key Words/Phrases.
2. Merge these separate lists of Key Words/Phrases into one coherent flow. This now becomes the outline for your summary notes.
3. Construct a set of comprehensive study notes following the order of your Key Words/Phrases outline previously developed. This strategy enables you to process your own learning far more effectively than copying somebody else's notes.
4. Complete assigned activities.
5. Answer the review questions. (Williams, 2001a)

Some of the following material is taken from the latest version of a thirty five page Study Skill Manual (Williams, 2001b) that has been in ongoing development over the last three years and which I give to all my students from grades 9 through 12 as a study and learning resource. The material in this study package is intended to help them with their assignments, and not necessarily be a complete learning resource as I am working with senior students who mostly just need their memories jogged. When working with new concepts such as this multi-stage learning model the readings referenced below are supplemented with general classroom work, or if necessary individual review.

Stage 1 - Initial Overview

The purpose of this initial stage is to have the students read through each of the assigned readings, there will always be a minimum of two–the textbook and the resource material that I have authored, in order to gain an overview of the material to be studied. Apart from class discussion describing the process, it is further described in the Study Skills Manual.

> Do a quick scan read of each primary reference, see pp. 2 & 3. At this time develop a Key Word/Concept list for each reference as shown on the right using three references as an example. On reading reference #1 list the key words and concepts as they appear in the first column. Repeat for the second reference, matching up the same concepts and inserting new ones as appropriate. Repeat for the next reference. This comparison listing is part of your work record. From these multiple lists merge the Key Word/ Concepts into a framework with an organized and logical flow. (Williams, 2001b, p. 12)

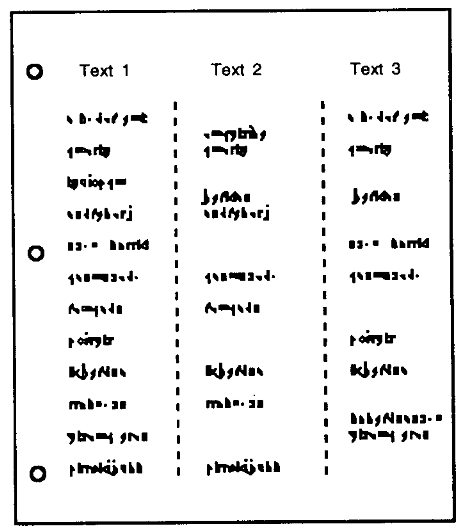

Figure 3. Schematic showing how to arrange Key Word/Concept lists using three sources

As the students start this task I remind them to keep their working list of learning outcomes at hand to keep themselves on task and not spend unnecessary time on topics that lie outside the realm of the learning outcomes. This working list includes any additional outcomes that I may have added. Topic 23 on resources is a good example as much of the textbook material refers to the geography and geology of mining in the United States, when I am more interested in the students learning about British Columbia and Canada.

Developing a Key Word list is a task that gives the students a great deal of difficulty and for the first few assignments while they are learning the process I spend time to review what is meant by Key Words and Concepts. For each topic I have generated such a list in a logical study sequence as an example, and have turned each list into an overhead transparency for review and discussion purposes. An example of a Key Words and Concepts list is shown in Appendix K for Topic 3, Igneous Rocks. By the time we have finished the first unit on Earth Materials, most of the students have a good grasp of what is expected. Before I next teach Geology 12, I will have developed a self scoring rubric for the students themselves to better assess how they are completing the task.

Stage 2 - Developing Study Notes

With the Key Words/Concepts overview in place the students are now in a good position to write their own study and review notes based on their previously developed framework. I tell the students that by Grade 12 I do not expect to have to teach them how to take notes, but if they are not sure to check the Study Skills Manual for review, work with their partners and then if they are still struggling, come and discuss the problems with me. All the way through this process I want the work to be student focussed, with students first of all helping themselves, secondly helping each other and only then using the teacher for help in order for them to develop as independent learners. I believe strongly after all my years of teaching that we do too much for the students and as such are not doing them any favours. We are too focussed on getting students through the course rather than being focussed on student learning. Referring to the Study Skills Manual,

> Taking this framework as a guide write a detailed coherent blended summary of the text materials, see p. 7. Whatever form of notes you prefer, whether paragraph form or hierarchical

> form, underline the key concepts/terms. The summary should fit into the length guidelines indicated for that topic - some may be limited to one page, others to three or four. This is the most critical part of the process as **you want to develop a resource that will be useful to you in later review and study**. (Williams, 2001b, p. 12)

I have found that it is important to provide length guidelines, particularly through the early topics. It tells the slackers that half a page is not good enough, whereas at the other end of the scale where students want to rewrite everything out again it lets them know that these are key notes that are to be a result of their processing and internalizing the reading.

As in Stage 1, I review in class what I would expect to see in the study notes, for example that all the Key Words and Concepts are covered, and definitions are in the students' own words not just copied from the glossary. On the topic of glossaries in textbooks, I deliberately do not provide one in my own writings as I want the students to engage in and internalize the reading, not just copy somebody else's definition. To help the students find the terms if needed, I had provided a complete index to the resource package by the end of the third year. Again, as part of the continuous and ongoing development of this curriculum, I expect to have a scoring rubric available for student or peer assessment of the notes by the time I next teach the course in February 2002.

Stage 3 - Reinforcing with Hands-On

The third stage of the process is to engage in some further reinforcement activity or activities. Such activities commonly involve hands-on work, or translation or interpretation activities. There may be some basic calculations of geological processes as per Learning Outcome A7. Frequently there will be slides from my own large collection to illustrate the different concepts within the topic. I have added close to 1800 specific geology slides to my collection during the last four years, to bring it up to almost 3000, about 95% of which I have taken. Slides, as mentioned earlier are a history of a teacher's own personal record of the learning and provide a much greater context for learning compared to abstract videos with a narrator who has little or no experience of the material - he or she just has a nice speaking voice.

Videos frequently cover far too much content in their twenty to thirty minutes for any other use but review. In my early teaching days I tried the "watch the video and complete the worksheet" approach, or "watch the video and answer the worksheet after". It did not take long to realize that very little learning took place and the learning that did occur was generally shallow and regurgitive. As a learning tool videos require a large amount of time to process. I have developed a system whereby I show a video and ask the students to just write down key words and phrases as the video is playing, enabling the students to concentrate on the video rather than trying to take formal notes. After the video has finished I ask the class to move into groups of three or four students and share their key words to produce a set of rough notes from that exercise. The students then watch the video again after having done this initial processing, and again jot down extra content, concepts or connections that they missed the first time through. The students then return to their groups and collaboratively develop a set of comprehensive notes for their own use. However to process a fifteen to twenty minute video this way takes a full 75 minute class period, so the teacher has to make a time-management decision as to whether the amount and quality of learning from the video is a good use of class time. When one considers these aspects of a video as a learning tool together with the generalizations that frequently occur, I use videos sparingly.

Using slides enables me to move at a slower pace in an interactive discussion with the students. It then becomes very easy for the students to take supplementary notes. I will limit a particular showing to between three and six concepts, but with multiple examples. For example, Topic 16, Volcanoes in Action, usually takes me about six class periods to complete. Part of the time during three of those periods we will watch slides. The first set of fifty slides focuses on just five themes within the general focus of types of volcanoes - shield volcanoes, cinder/scoria cones, composite volcanoes, dome volcanoes and rift/fissure eruptions, with multiple examples of each one and within a thirty minute time frame. Thus it is not just one picture in a textbook, or one scene in a video, but rather thirteen different cinder cones are illustrated from the west coast of North America, Hawaii, Australia and New Zealand. The second set again focuses on only five themes - lava flows such as pahoehoe, aa, and obsidian, columnar jointing, lava tubes, pyroclastic deposits, and intrusions. Four of the five themes of the third set are all related to damage and human impacts - caldera formation, blast damage and lahars, lava flows, and pyroclastic deposits, while the last theme is geothermal effects.

Not only does this approach, as old fashioned as it might be for is not Power Point all the rage, allow for time, it also allows for discourse. Each year the slide sets change somewhat depending on where I or my friends have travelled. It is easy to maintain the database now it is started and to print out a list of the slides with descriptions in the rare case of needing a Teacher-on-Call, or in case a student has been away he or she can then use the slide set and descriptions in my classroom or in the library during a study block if either I or my room are not available.

The other key component of this third stage is the hands-on activities. The foundation topics such as minerals and the different rock families, as well as weathering and volcanism all have extensive sample collections. In the case of the minerals I am building up the collection of hand size samples just keeping the small chip size for destructive testing such as streak and hardness. For the most part these larger samples have to be purchased from various sources and like a good home shopper the teacher has to know the price ranges of the different samples. For the rocks, although I have had to purchase one or two, most can be found if one wants to do the research and the travelling, as described earlier.

For many of the rock identification samples I have knocked off a tiny chip from a corner and cemented it onto a microscope slide, initially using modelling clay covered with a white glue coating as the cement but now using silicon sealant. These are labelled with the same code number as the large specimens but are designed for use with a dissecting microscope so that the students have a chance to compare the macro and micro views, and better learn how and why that particular rock is formed. When the task is completed I review the specimens with them and leave the samples out on the counter until the end of the topic so that those students who wish can come in and review their identification or ask me further questions as needed.

For the minerals and rocks I can, if so inclined and the school has the money, at least buy what I need. When working with Topic 13, The Fossil Record, I am able to work with specimens I have bought for the school, fleshed out with those from my own personal collection. In other topics such as Topic 6a, Weathering, none of the samples that I provide for the students to use can be purchased, I have to keep my eyes open for materials than can be useful. Similarly, most of the specimens I have for Topic 16 Volcanoes in Action and Topic 23 Mineral, Rock and Energy Resources, cannot be purchased and have to be opportunistically collected.

Most of these rocks I have collected during extensive travels and field excursions during the past four years, as I never travel anywhere without my backpack of equipment such as picks, chisels, hammers, safety glasses, hard hat, collecting bags, marker pens, cameras, and a first aid kit. As mentioned earlier, in my role as teacher scientist I have to research the locations which I am visiting, acquire the necessary reports and field guides either through direct purchase, or by photocopying the relevant pages for reports that are long out of print. With the older field guides, roads and trails are rebuilt and relocated changing kilometre reference distances for example, roadside pullouts have been relocated, the land is no longer accessible due to changes in ownership, and frequently one can never find the rock exposure that is being described. However, as an educator the most important aspects of collecting ones own samples or taking ones own slides are the modelling that it provides and the stories it supplies. The stories supply a context that can never be obtained through commercial material.

Stories

Many of the rocks are relatively mundane, particularly those for which the principle use is basic identification and do not require any more contextual knowledge other than the location. Even this low level of context, coupled with the samples and the 35 mm slides, reinforces that this is a hands-on course about learning. However even this is a useful teaching tool because it exemplifies one of the many ways in which the good geology educator models their own love of learning.

With some of the more specialized rocks, structures or formations, the contextual stories take on a greater importance. The stories may reinforce the research aspects, or the hiking and outdoor work of a field geologist, or they may reflect that the presence of this particular sample in their classroom is the cumulative effort of a number of different people in various locales together with a good dose of serendipity and tenacity. The following three stories illustrate some of these different aspects of story telling.

Myth of the Giants

As the Science 8 curriculum and resources evolved during the 1970's, Prentice-Hall of Canada published in 1977 the second edition of Introducing Science Concepts in the Laboratory, Schmidt and Murphy (Ed's). On p. 205, Fig 52 shows two views of the hoodoos at Hoodoos Provincial Park, just east of Drumheller, Alberta. One view is an overview of the site while the other is a close-up of the top of a hoodoo and the cap rock. During this time period, the British Columbia Teacher's Federation released Slide Set M-1, a set of 103 geology slides to enhance the Earth Science components of the Grade 8 and 10 curricula. This set included a slide of a single hoodoo, taken from below. These pictures were the only information I had concerning the size of these structures and I thought they were many metres high.

In 1992 I had the chance to visit the site and take my own slides, and was amazed at how small these hoodoos actually were, only three metres or so high. A couple, who happened to be visiting on their honeymoon, graciously consented to stand beside one of the hoodoos while I took their picture to indicate scale for one of the slides. When teaching I show a slide of a bare hoodoo and ask my students how big they think the structure is. After some discussion they are quite astonished to see the slide with the people in, as like me, they had thought that the structures were much bigger. This leads on to further discussion on the need to indicate scale and that very few textbooks take this issue seriously.

Glass Lava

A common theme in many textbooks is that obsidian is a silicilic/felsic lava that has cooled so quickly that its atoms remain frozen in a random state to form a natural volcanic glass. At Newberry National Volcanic Monument, just south of Bend, Oregon there are three obsidian flows inside a large caldera. The largest of these, the Big Obsidian Flow, is close to the access road and there is a short circular trail across the flow near its end. There is also a steep, poorly maintained road up the back of the volcano to Paulina Peak, the highest point on the rim of the caldera from where one has an excellent view of the entire flow. By showing slides from ground level, as well as from the caldera rim, the students get a good sense of the size of this flow leading to discussion about the validity of the textbook explanation. Furthermore, along the ground level trail there are very clear examples of the obsidian degassing to form pumice. I also add that a muffler bracket broke off as I was coming back down the mountainside, and at the bottom where the road was level I used an old coat hanger to wire it back up into position, reinforcing some of the hazards of field work.

Serendipity and Volcanic Bombs

During the summer of 1998 I visited some British Columbia teacher friends who were on an exchange assignment at Drouin, about 100 km east of Melbourne, Victoria, Australia. My friends and I were invited over to Robert's house for lunch one Saturday, the day before I was to pick up a rental car for a week of travelling west along the scenic coast road. (I have changed all names in this story). During lunch Robert handed me a dark wet rock to identify, explaining that it had been sitting in his aquarium, and challenged me to identify its origin. I correctly identified it as part of a volcanic bomb with a core of green olivine crystals, told him that I had never actually seen one before, and asked where he had found it. He explained that it had come from Mortlake, a small village west of Melbourne, where he had taught before coming to Drouin. As we left he kindly gave me his bomb as a souvenir of the visit, especially as I explained that I would like to have one for my resource collection back here in Canada.

Three days into my trip I awoke in the coastal town of Warranambool to a cold foggy morning, and a missed breakfast as I had not yet mastered breakfast protocols in the Australian chain motels. On planning my day I noticed that Mortlake was only forty kilometres away inland, and probably free of the sea fog, so, on an empty stomach, not even a coffee, that is where I headed. Coming into the small community one passes under large overhead signs proclaiming "Mortlake: The Olivine Capital of the World" so I knew I had found the right place. After having some breakfast of questionable quality, I waited for the local Tourist Office to open, and at 10:00 am wandered in as the doors opened. I created great excitement when I explained that I taught senior high school geology just outside Vancouver, Canada, and was interested in obtaining some further examples of olivine and volcanic bombs.

After some discussion the ladies in charge made a couple of phone calls and explained that somebody would be over in about fifteen to twenty minutes. In the meantime would I like a cup of coffee, and yes, I was an excuse to open a fresh package of Peak Frean cookies, as they never get visitors from

Canada. Jim arrived after coffee and directed me to a complex of three cinder cones to the north of the village. We drove up to a flat spot on the flank of one of the cones that was being excavated for road material and where we spent the next three hours "fossicking" or looking for bombs. I was quite successful, collecting some larger sections about 12 cm across, and a few small but complete bombs. While we were standing on the cinder cone Jim looked east and identified Elephant Head, another cinder complex, but suggested that I head west towards two other cinder cones, Mt. Rouse and Mt. Eccles. I took him home and thanked him for his time, returned to the Visitor Centre and thanked the ladies there for their help, and then headed west to Mt. Rouse.

Mt. Rouse turned out to be a rather plain cinder cone with a small summit crater. From the summit one could see Mt. Napier, another cone to the northeast, but more exciting I had an edge-on view across the southern end of the Grampians Mountain Range, a complex of thrust fault mountains. The overthrust stacking of the sedimentary layers showed up clearly in a way that one can rarely see in the Canadian Rockies, formed in a similar manner. From Mt. Rouse my next destination was Mt. Eccles where I saw lava channels and tubes. On returning to the coast road I passed over lava flows from Mt. Napier that had great heaps of broken lava blisters on the top resulting from gasses building up under the crust of the flow and periodically exploding out through the surface. It was dark by the time I reached the Coast Road, only 40 km from where I had started off that morning, but what a serendipitous day it had been, all because of a rock in Robert's fish tank.

The stories not only create a context, but also enable much modelling to take place of the teacher as scientist, researcher, explorer, opportunist, and a lover of learning for example, all aspects that are so important in terms of bringing the topics alive. The only danger in terms of student learning is that some learners tend to hang onto the stories per se and that I have to reinforce that it is the underlying concepts behind the stories that are truly important; the stories place the learning in context.

Stage 4 - Reviewing the Learning

The last stage is to answer conventional questions that directly relate back to the learning outcomes and frequently contain examples of short answer questions similar to those appearing on the Geology 12 government exam. The questions always reflect the range of readings as well as the various activities and visual materials that were used. By the end of the questions the students are asked to complete their self-monitoring chart, Appendix F before they write some sort of test or assessment. By the time that these questions are completed, this will have been at the very least the fourth time, in some cases the seventh or eighth, that they have worked with the topic material, each time using a different approach to learning. The best assessment of this approach happened last year when a student who was working on his review questions for one of the topics stopped me as I walked past his desk and indicated that the questions were so easy as he had, without realizing it, learned so much.

One of the time consuming tasks of conventional teaching practices is dealing with such tasks as answering questions. Taking them up in the front of the class is time consuming and in some cases a waste of time if the work has not been done. Taking the approach that the questions are due on a specific date and when that date arrives I spend a few minutes checking for problems that from experience I have previously identified. For example, I know that Bowen's Reaction Series (Topic 3) is going to give them some problems the first time through. For the next ten minutes or so, those who have finished their topic work come and show me their completed assignment which I then initial and record on a chart in my assignment record. When all who want their work signed off have checked in with me I post a set of detailed answers on the bulletin board. Those who are signed off are instructed to self check their answers and do their corrections. These answers stay up for forty eight hours.

If the students come to me to be signed off some time later I will initial their work together with the word "Late" and put an "L" in my record. It is up to them to ask for the answer key to check their learning.

This gives me a direct assessment of the students' work habits for future discussions with the student, the councillor, or the parent. Not having to waste the class's time with oral or blackboard answers is one technique that gives me the extra time over the semester to do the hands-on work and enrichment that I believe is so important. I have also discovered that when I type out the answers to the questions I am much more careful and more complete compared to traditional oral work. Posting the answers gives the students reflection and collaboration time. As the students' answers are signed off on the due date, and the answers to the assigned questions are printed out and posted on the classroom wall for them to self check and correct the process firmly places on the student that each one of them is responsible for competing their work on time and for doing their own learning.

For some topics there will be an interim test at the end of the topic, particularly during the skills topics covering minerals and rocks. Each of these shorts tests has a written and hands-on component. These tests are more formative in nature and intent and are balanced to only count as a very minor part of the students' grade. After the test has been scored, the students, particularly in the hands-on component are encouraged to spend time reviewing the samples with respect to their incorrect answers, to try to work out the identification problems themselves, but if necessary discuss with me. As part of the resource package, I give the students a copy of the charts and tables from a typical exam data book, and they are expected to use any of that information that is relevant during any test, to get them used to working with such a resource during an exam.

Most students are not used to this sort of reflective behaviour where a test is used as an integral part of the learning process, and it usually takes about three to four topics and their respective tests for the students to start to realize the value of this process. If the topics are fairly short, but the overall unit is quite long as occurs with the Surface Processes Unit, I bundle up two or three topics for the in-between test. Returning to Baird's (1997) comment that, "poor learning is a result of poor decision making", those students who do not use their mini-tests as a learning tool or do not complete and correct their assignments certainly exhibit poor decision making skills of which they are reminded.

The final assessment for a large topic, or a unit, consists of some sort of written exam usually divided into two sections, multiple choice and short answer in similar proportions to what the students will experience on their government exam. I usually add in other types of questions that will not appear on the exam but further challenge and evaluate their learning, such as a few true-false type but where the students, if they decide a statement is incorrect, have to write it correctly without changing the integrity of the question. Just turning the statement into a negative is not allowed. Sometimes I use multiple choice questions in which the students have to explain the reasoning behind their answer choice. It is always interesting how such simple techniques really sort out those who truly know their material. I always separate the marks out in my record chart into two columns, one for the multiple choice, the other for the short answer, as this gives me further clues as to student learning and is useful evidence when preparing written reports.

In some topics a hands-on exam for identifying minerals, rocks, or fossils is appropriate, whereas at the end of the Surface Processes Unit part of the assessment will be to look at a set of twelve to fifteen slides identifying the features that I point out, and naming and explaining their formation, in a simulation of the picture questions of the Geology 12 Final. I do not use the Topic assignments as a significant evaluation of student learning since most of the work has by its nature been collaborative and interactive, and if the work has been completed on time the answers should have been checked and corrected. Thus, by the time the students have finished a topic the assignments should be all completed and corrected and therefore only useful for assessing work habits. I do collect in some assignments but just to evaluate completion of specific components, such as a check on the key words and summary notes, completion and correction of a data table, a graphing assignment or completion of specific worksheets and these provide about twenty five percent of the academic marks record. Not having to mark all parts of all assignments frees up further time for resource development, specimen management, and inventory control, all important teaching tasks with so much resource material.

This chapter has outlined a multi-stage learning model that has been used to focus on student learning rather than the teacher teaching, and that fluctuates between being transactional and transformative rather than focussing on the transmissive. The model encourages students to take responsibility for their own learning and gives them practice in some specific strategies for becoming independent and lifelong learners. From the perspective of the educator the processes free up time for more hands-on and enrichment work that is so essential to a topic like geology, as less time is wasted on traditional classroom activities such as general assignment marking or a lot of routine checking of work. These are grade twelve students who at the end of the course will be leaving high school and moving out into the bigger world in which they will be expected to make their own decisions and live by the consequences. Educators who still play 'mother' at this level are not doing their students any favours, even though the mothering might be what enables the student to 'pass' the course. The next chapter will look at three different focus topics in more detail in terms of their content and structure, and the different issues around each.

6. Multi-layering in Action

In the earlier chapters I described the traditional rigidity of the science teaching culture in terms of beliefs in absoluteness, stylized rigidity of written work, a determination that there is a right answer, reliance on textbooks of questionable effectiveness at facilitating student learning, and classroom activities that confirm with predictable right answers. Science is considered to be abstract apolitical theory with little connection to time and place with negligible reference to social and historical issues within a Canadian context. There is little or no acknowledgment within the system that science is a process of ever changing human constructs in our attempts to explain the world around us. Students have been indoctrinated into this system through a factory structure of fractured batch learning within boxes of space and time. By the time they have reached the senior grades students have formed very rigid beliefs concerning their role and the role of the teacher. Learning in science is frequently considered to be a linear process of teacher lectures, interspersed with correct activities leading to student recall and regurgitation during the next test–and this is referred to by the system as learning.

For much of my career I had taught general science at the junior high level and after a two year period away from the classroom I knew I would be returning to a grade nine to twelve school. During those two years I had developed a vision of teaching for learning in which a central premise was that if the depth of learning and understanding improves then exam scores should also improve. This involved developing a model of learning matrices in which multi-level approaches to concepts would lead to greater internalization, within a framework of metacognitive strategies that encouraged the students to become more independent learners taking charge of their own learning. At the junior high level I had developed and worked with various parts of this model but it needed a new school and new course for me to work the process through in its entirety. Coming to a new school to teach a completely new course, Geology 12, gave me the opportunity to fully develop and implement that vision.

Chapters 4 and 5 outlined the broad framework of the model and explored how it has evolved over time in terms of teaching, learning and resources. In terms of teaching, I have stepped back significantly from transmission to a more transactional and transformative approach in which students are given more discretion to manage their time. In terms of learning I have developed a multi-layered model that exposes students to concepts a minimum of four different ways, developed strategies for assessing prior conceptions, reflecting on learning, and building on mistakes, made integrated hands-on work a significant part of the learning process, and developed local and Canadian contexts. Resources have been collected from many parts of the world, necessitating extensive research on my part, and this has entailed developing strategies for their use as well as inventory and management control in a classroom that has very little storage space. This chapter takes this multilayered model and focuses on three topics, 3b Igneous Rocks, 12 Volcanoes in Action, and 23 Mineral, Rock and Energy Resources to illustrate in more details some of the various approaches that have evolved and touch on the scope of the science research involved. In all three topics, the final questions stage follow the generic pattern of being based directly on the learning outcomes and ask the students to interpret the content and processes of the topic, rather than just being low-level recall.

Topic 3b - IGNEOUS ROCKS

My writings for this section cover the same material as the text, except for the insertion of local examples. However in order to make the writing more learner friendly I have used a number of different writing strategies not commonly found in this level of text material. There are a number of major concepts within this topic:-

1. Crystal size is related to cooling rate - faster the cooling the smaller the crystal structure, which relates to formation. Surface lavas cool faster than molten masses deep within the Earth.
2. Rocks are characterized by the proportions of their minerals, or where the minerals cannot be individually identified by eye, by the colour which correlates with mineral content.
3. Lighter coloured rocks are higher in silicon (sialic rocks), while darker coloured rocks are higher

in iron (ultramafic rocks). The colour varies along a continuum.

4. The volcanic rocks have a number of different types based on their texture that is related to gas and water content at the time of the eruption.

Crystal size is illustrated with two sketches shown below. The granite sketch on the left indicates that this rock is made of a mixture of crystals of different minerals, whereas the basalt sketch, right, indicates that the structure is of uniform colour with very fine crystals, a concept reinforced by the simple technique of making the rock look as though it is being viewed through a magnifying glass. The reader should keep in mind that there will also be a number of actual large samples for the students to work with. The textbook shows a photograph of each type of rock sample with no indication of the magnification of the picture.

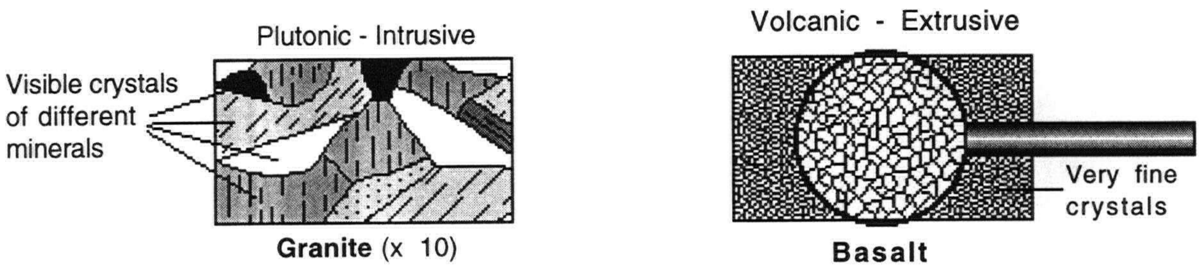

Figure 4. Sketches showing structural differences between granite and basalt.

The concept of colour and composition changing along a continuum is illustrated by the use of arrows as shown in the following example for the large grained plutonic rocks. The names of the different rocks are positioned at the appropriate places on the continuums. I have also included a similar diagram for the volcanic rocks in the resource guide but not illustrated it here.

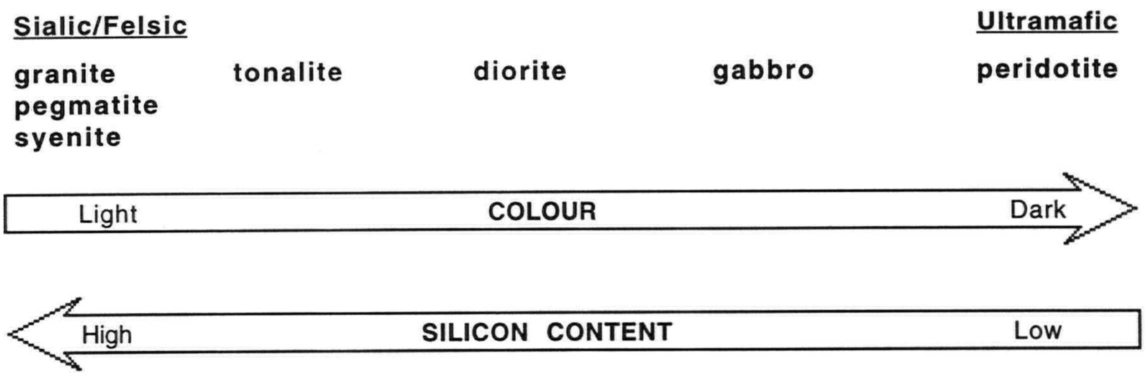

Figure 5. Corelation between colour and silicon content for plutonic rocks.

In order to describe each of the major types of rocks within each category I separate them out into charts rather than burying the descriptions with the text. The charts for the principle plutonic rocks is shown below and are divided into three columns as shown to clearly relate the concepts of colour and minerals.

Plutonic Rock	**Overall Colour (Index)**	**Majority Minerals Present**
Granite	light, few dark minerals (10)	Noticable glassy quartz and light orthoclase (K) or albite (Na) plagioclase feldspars (felsic/ acidic). The few dark minerals are biotite or hornblende.
Pegmatite	light, few dark minerals (10)	An extremely coarse grained light coloured phaneritic rock, similar composition to granite.
Syenite	light, few dark minerals (15)	No quartz, pink, grey and white orthoclase (K) and plagioclase (Na) feldspars (felsic). The few dark minerals are biotite or hornblende.
Quartz Diorite (Tonalite)	medium, similar proportions of light and dark minerals (20)	Light minerals, mostly albite (Na) feldspars with some quartz and plagioclase feldspar. Dark minerals are hornblende or biotite.
Diorite	medium to dark, more dark minerals (25)	Feldspars, mixture of Na and Ca plagioclase. Dark minerals commonly hornblende, some pyroxene.
Gabbro	dark grey to black (50)	Mostly dark magnesium and iron minerals, no quartz and some calcium feldspar (mafic).
Peridotite	dark black (95)	Mostly pyroxene and olivine with a little calcium plagioclase (ultramafic).

Figure 6. Relationship between colour and mineral content for plutonic rocks.

A similar chart has been drawn for the basic volcanic rocks that are uniform in colour and in which individual mineral grains cannot be visually identified, except that I have deleted the minerals column and included a column on relative silica content and another on viscosity for later use when we discuss volcanoes.

Volcanic Rock	**Overall Colour**	**SiO_2**	**Viscosity**
Rhyolite	light - pale grey, cream	High	High
Dacite	greenish grey, grey	Medium	Medium - High
Andesite	grey, light brown	Medium	Medium - Low
Basalt	dark - brown, black	Low	Low

Figure 7. Relationship between colour, silicon content and viscosity for volcanic rocks.

In both charts I have included extra rocks that are not listed in the learning outcomes. The students are quite capable of learning two or three more, but I only formally assess their knowledge of the prescribed rocks. The special types of volcanic rocks–porphyry, obsidian, pumice, tuff and volcanic breccia, are separated out in their individual paragraphs describing colour and texture. For obsidian I also add a qualifying rider suggesting that its texture is not simply due to cooling rates and that there must be a compositional effect taking place.

When working with the large samples, the students find it relatively easy to make the connection that plutonic rocks have large crystals and volcanics have microscopic crystals. The charts make it much easier to then make the connections between colour and minerals. One has to keep in mind that only about 30% of my students have taken Earth Science 11 so for the majority of the students their knowledge ranges from sketchy to non-existent.

In this topic there are two aspects to the hands-on component. The first part is to work in small groups with a number of igneous rocks, in many cases they have both macro and micro specimens, describe the characteristics of each and then try to put a specific name to each one. Although the students have worked with minerals in the previous topic, this is the first major assignment at specific identification and I treat it like a detective exercise - their observations become their clues, and the better their observations the more useful the clues will be. I currently have forty large igneous rocks, fifteen plutonics and twenty five volcanics and the students have two class periods in which to work with them, so for the most part there are multiple examples of each. Since these rocks lie on a visual continuum there can easily be debate as to whether a particular sample is a diorite or a gabbro for example, the answers are not always clear cut and predictable. At the beginning of the third class we review the answers and the students are then encouraged to go back and review the specimens to clarify their learning.

The next part of the exercise is a self assessment process to develop a dichotomous key as outlined in the specific instructions below. This is given as a combination class - homework assignment to:

> Develop a graphical style of dichotomous key for the sixteen different igneous rocks that you have been working with in this unit:- Use the key properties that you worked with when identifying these rocks. Your key should be able to be used by a stranger unfamiliar with rocks.

After the students have completed their keys they do a self assessment in partners. One partner goes to the storage bins and takes out a rock for the other partner. The student with the rock has to show his/her partner how that rock can be keyed out on their chart, tracing the pathway with a pencil. The process is repeated for the other partner with a different rock. If the sample cannot be cleanly keyed out then it is back to the drawing board to redesign the key.

So in both the rocks and the identification key exercise the students have a chance to reflect on their initial learnings and return for further review. In terms of the identification key exercise the students are allowed to use the final version of their individual keys with their hands-on assessment so there is some incentive to do the task so the product can be useful. Although it might sound relatively easy to design an identification key this is a "critical thinking" task that quickly identifies how well the students have understood the concepts of texture and composition.

I have deliberately kept away from the phrase "critical thinking" as within the context of the school environment it has become quite a hackneyed expression that is frequently misunderstood, Bailin, Case, Coombs and Daniels (1999a). I use it here in the context of the Bailin et al. definition that

> teaching critical thinking is largely a matter of teaching students to make appropriate use of the concepts, standards, stratagems and procedures our culture has developed for disciplined thinking and increasing its fruitfulness. . . these concepts and standards are embedded in complex practices of critical deliberation and discussion. (1999b)

Much of this critical thinking can be delivered through the appropriate use of the higher levels of Bloom's Taxonomy of Education Objectives, (De Cecco, 1968). Already, this early in the course the students have been encouraged to engage in critical discourse with each other, calling me into the discussion as necessary, in terms of their analysis of the different rocks. To take those aspects of identification and construct a dichotomous key requires a clear understanding of the properties/evidence used in their original detective work to develop a workable identification key that another can use. Construction of such a key demonstrates the use Bloom's levels of analysis, synthesis and evaluation.

As another example of how I have integrated critical thinking into the programme, Appendix J lists the variety of specimens collected and used in Topic 6a, Weathering. Sample 10 is a weathered vesicular basalt, while specimens 6 and 14 are examples of weathered gabbro. The students are not given this information but instead they are asked to identify the rock and infer its geologic history, with a brief listing of the evidence - a bringing together of the knowledge of minerals and rocks that they should have learned in Topics 2 - 5, combined with the new learning about how minerals and rocks can chemically and physically change over time.

The idea that one can have a learning structure that builds in review and correcting ones work is quite new to the students and for these first few exercises they have to be encouraged that this is one way of taking charge of their learning. The students are so used to doing an exercise/activity, marking the work and then moving on not realizing that working through mistakes can be a powerful learning tool. In terms of this activity the students have engaged in an overview, construction of detail notes, interspersed with class discussion and slides of igneous rocks in the field, engaged in a collaborative process of identifying a number of large samples, reflected on the accuracy of their identification and problem solved how to improve the process, developed through a critical thinking exercise the co-ordination of their learning into a dichotomous key that in the end they will be able to use in the assessment of their own learning–learn, practice, reflect, correct, and apply. The last stage of the model is to answer and correct the review questions, which are generally a reworking of the original learning outcomes in question form.

In terms of written work I treat most as journal work written in the first person and in which the topics do need some core identification such as the date the work was started, the title of the topic and the names of the people working on the topic. These are learning activities in the true sense not scientific experiments and so I do not insist on formal stylized lab write-ups. I do evaluate their written work in terms of communication and presentation skills, using the model that I am their work supervisor and in that role I need to periodically read and review their record of 'work in progress' to write a report for my supervisor. If I cannot read or make sense of the work it has to be rewritten to an acceptable standard before it can be signed off as being completed. At the beginning of the course I do these work in progress checks in the classroom at least once per topic, but later on in the course I find for the most part that spot random checks work just as well and I can focus my attention on those relatively few students who still need more direction. I should add that discussions of acceptable standards of work also take place at the beginning of the course and periodically throughout if I sense standards are slipping.

In this early assignment, the students have their second experience of the multi-level approach to learning. They have a posted schedule outlining a reasonable approach to completing the assignment on time colour coded as to which has to be done in class and which they can do either in class if they have time or as homework, a self check of their prior knowledge (Appendix F), the chance to review and correct their work at different stages of the assignment, and a powerful self assessment tool to probe for deep understanding that they can later use for their assessment. At this stage of the course I am somewhat transmissive in terms of keeping to the schedule and doing the review and corrections as the students are just learning what it can mean to take responsibility for ones work and learning. By the time we have finished the first unit, principally Topics 2 - 5, the students are starting to understand the pattern and I back away from the regular intervention unless a student starts to fall behind and be at risk of potentially failing. After this initial unit spent developing and reinforcing the multiple layered approach the students start to become more confident in their abilities and once we have introduced a topic and set out a schedule they come into class and get on with their work without a lot of further instruction.

Topic 16 - VOLCANOES IN ACTION

In the introductory overview to this topic, Appendix E2, I have added two extra learning outcomes C 9 and C10 to those listed in the IRP, and have also included a specific section referring the students back to Topic 3 Igneous Rocks and Topic 5 Metamorphic Rocks for review. While the resource list for Topic 3 Igneous Rocks (Appendix E1) was relatively short, the resource list for this topic is much longer and is more varied. The listed resources consist of print materials including an article by Hickson (1990) on the eruptive activity of three local volcanoes, Mt. Meager, Mt. Garibaldi, and Mt. Baker, slides, hands-on samples and a video. The listing for internet sites is also significantly longer and again contains sites for local context.

In order to create both local context and interest I open this section with three travel style paragraphs describing a road trip south along the length of the Cascade Range of volcanoes, down the west side through Washington State and then crossing over to the east side and the high interior plateau through Oregon. The topic continues with a major review of volcanic rocks, taken straight from Topic 3. Once the students have reviewed the basic volcanic rocks and their chemistry, particularly with reference to silicon content and viscosity, the different types of volcanoes are discussed, together with sketches to reinforce the structural differences. Instead of using the term "rhyolitic" magma to indicate those of highest silica content, Thompson et al. (1995) use the phrase "granitic" magmas which the students find confusing at this level as they associate the term granitic with a coarse-grained plutonic structure rather a fine-grained volcanic structure. Furthermore, the textbook does not mention the dome-type volcanoes that form from these high silica magmas.

In terms of helping to relate structure to type of volcano, the class text only has one cross-sectional diagram, that of a composite volcano, and that is not very easy to interpret as the diagram tries to portray a three dimensional perspective that does not agree with the accompanying photograph of a composite volcano. All three texts are quite simplistic in their discussions of composite volcanoes and do not indicate that the lava chemistry of such a volcano can fluctuate over time leading to different types of eruptive behaviour. Mt. St. Helens for example has had relatively quiet eruptions of low silica basalt as well as explosive eruptions from relatively high silica dacite lavas, (Pringle 1993). Apart from the black and white line drawings, the Resource Guide material is supplemented with 35 mm slides as described earlier.

The Topic 16 text continues to describe the distribution of volcanoes and I have included maps and charts focussing on all the volcanoes along the west coast subduction zone, the world is not cut off at the forty ninth parallel. It continues to describe secondary volcanic effects and hazards and the concept of predicting volcanic activity. The topic closes with a discussion of internal magma behaviour, the formation of batholiths and associated intrusive structures, with a review of contact and regional metamorphism.

Another technique that can be used to break up text is to quote from other authors. I was so taken by Alt and Hyndman's description of cinder cones in their 1978 book Roadside Geology of Oregon that I included it in the students' guide. I realize that the quote is non-metric but I find it so expressive.

> These are the little fellows that start erupting off in a field somewhere, cough chunks of bubbly basalt magma out of their vent until they build a cone of cinders a few hundred feet high, and then finish the eruption by producing one or two lava flows that emerge from the base of the cone. Once they quit they never erupt again. (p. 136)

This technique not only breaks up the writing, but also models that the author is prepared to use and correctly cite other work.

As with other topics the activities reflect specimens that cannot be purchased and must be collected by me or from other sources, usually friends, again after extensive research followed by the good fortune to find what one is looking for. I have listed below the source materials for the different activities of this topic as an indication of the extent and variety of the resources– the numbers refer to the different activitystations.

1. Obsidian, pumice and a specimen of in-between texture - central Oregon
2. Lavas from Oregon, Washington, north-central British Columbia, Hawaii, California
3. Columnar basalt porphyry - Mt. Baker
4. Basalt porphyry - Mt. Baker, dacite porphyry - Mt. Garibaldi area
5. Cinders from north-central British Columbia, Mt. Garibaldi area, Hawaii, Mt. Vesuvius, Mt. Shadwell, Victoria, Australia
6. Pumice samples from different places along highway 97 in south-central Oregon.
7. Cemented Mazama ash near Princeton, British Columbia. Fragile ash sample from a point close to Crater Lake, Oregon.
8. Mt. St. Helens ash from Spokane and Yakima, Washington

   Two samples of Mt. Mazama ash - Princeton, B. C. and Hwy. 97C north of Falkland B. C.

   Mt. St. Helens Y ash, Hwy. 97C north of Falkland B. C.
9. Both dacite samples from Mt. Lassen, California during its last eruptive phase.
10. Basalt intrusion in quartz diorite, near Ioco, B. C..
11. Four pumice samples - the 1980 Mt. St. Helens eruption, the AD 186 Taupo (New Zealand) eruption, the 5680 BC eruption of Mt. Mazama (Crater Lake), and the 700 000 BP Tumolo eruption from near present day Bend, Oregon.
12. Weathered vesicular columnar basalt, Hwy 97, central Oregon
13. Volcanic bombs from Mt. Shadwell near Mortlake, Victoria, Australia.
14. Lava from the rebuilding dome of Mt. St. Helens.
15. Silica sinter from the Rotorua geothermal area of New Zealand.
16. Three sand samples from the islands of Oahu and Hawaii in the Hawaiian chain.

Station 1 clarifies for the students that pumice and obsidian are chemically the same particularly as this concept is reinforced with the transitional sample, whereas stations 2 to 5, and 12 illustrate the variations in basaltic lavas. Stations 13 and 16 also review the weathering rates of minerals and Bowen's Reaction

Series from Topics 3 and 6. Thus Topic 16, as well as providing experience of a wide variety of volcanic products, is a good example of the matrix of learning at work.

Not only is this a divergent collection of hands-on specimens that leads to a greater understanding of the different types of eruptive products, most have a contextual story, bringing the student tasks to life. Since the students know that I have collected most of these then I am further modelling that I am not just their teacher but am also a researcher doing field work and keeping up with my subject, a powerful motivator for learning. If a teacher is not able to take students on extensive field trips, an ideal way in my opinion to learn about the earth, then I believe that those field trips must be brought to the students through the use of samples, slides and personal narrative to create the context for learning.

Topic 23 - MINERAL, ROCK AND ENERGY RESOURCES

This topic links well with, and allows for further review of, the earlier topics on minerals and rocks and intrusive magma activity, Topics 2 to 5 and Topic 16, an important aspect of the matrix approach to reinforcing student learning as the class at this point in time is coming to the end of the course at which time I revert to traditional mode and spend the last five class periods on formal review for the Geology 12 Government exam. Thus being able to pull so much of the early material together at this time is a useful process that would be lost if I had kept to the topic order in the IRP. I should point out that although the IRP does not prescribe a particular order for teaching the topics a number of my peers either follow the IRP sequence or follow the chapter sequence in whatever text they are using.

This topic is not covered very well in any of the three texts that I have been discussing. It can be seen from the outline, Appendix E3, that in terms of the text I use the information is scattered through three different chapters, with the main chapter, Chapter 22, having an exceedingly heavy United States emphasis. Montgomery et al. (1997) has a similar layout to Thompson et al. (1995) with a chapter specifically devoted to resources whereas in Monroe et al. (1998) the content is even more fractured in the way the material is presented in small segments throughout the book. As much as I approve of the idea of integration of content and process, the content is difficult to pull together in terms of the specific prescribed learning outcomes. The supplementary print resources listed in the overview have mainly come from industry.

The Resource Text reviews, from Topic 2, the properties of major ores of Canada in chart form. The chart relates the chemical formula to the type of ore as the chemistry of the ore is one of the factors determining the process by which the crude metal will be produced. As stated earlier, presenting data in chart form enables the student to readily synthesize the information and compare the different properties, compared to embedding the content in tightly written text.

Metal	Mineral	Formula	Type	Colour
Copper	Chalcopyrite	$(Cu,Fe)S_2$	sulphide	yellow gold
	Chalcocite	Cu_2S	sulphide	grey
	Bornite	Cu_5FeS_4	sulphide	reddish purple
	Chrysocolla	$CuSiO_3{\bullet}2H_20$	silicate	greenish blue
Iron	Hematite	Fe_2O_3	oxide	reddish brown
	Magnetite	FeO,Fe_2O_3	oxide	black
	Limonite	$2Fe_2O_3{\bullet}3H_2O$	oxide	yellow to dark brown
Lead	Galena	PbS	sulphide	battleship grey
Molybdenum	Molybdenite	MoS_2	sulphide	silver grey
Nickel	Pentlandite	$(Fe, Ni)_9S_8$	sulphide	yellowish bronze
Zinc	Sphalerite	(ZnS)	sulphide	greyish brown

Figure 8. Some properties of common ores.

This is followed by a simple flow chart that outlines the processes from exploration through to fabrication to give the students a contextual overview prior to learning about the different stages in more detail. Such graphic overviews are not used enough in my judgment when describing sequential processes as they provide a ready mini-matrix in which the different stages can be contextually related to each other.

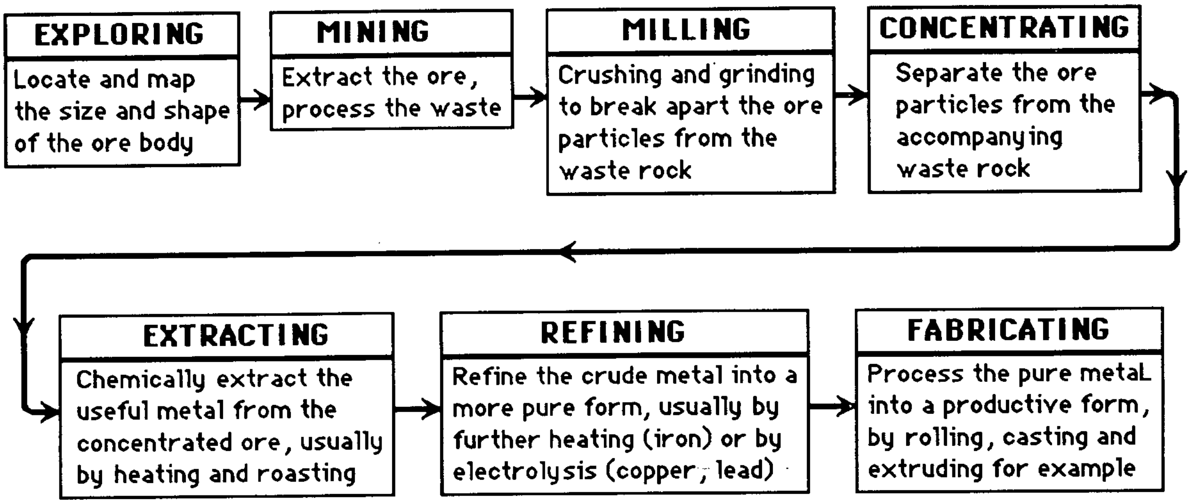

Figure 9. Flow chart showing major stages from exploration to fabrication for metal ores.

I did have something of an advantage developing this topic as I grew up in an iron ore mining area of England in which the ore was not just mined but the other needed materials such as coal and limestone were shipped into one of the largest steel making complexes in the United Kingdom. While studying for a degree in metallurgy I visited this complex many times. Also, most of my extended family lived in the coal mining area of South Wales and my grandfather had even worked in the mines and eventually died of black lung disease. With this personal background I find that the Resources topic is a great chance to really focus on both historical and social context as called for by the Science Council of Canada (1984). The summer prior to starting my current position I arranged my holidays as two road trips looking at current as well as historical mining activity in British Columbia and south-west Alberta. One trip was along the southern route from the Lower Mainland across into the historic Crows Nest coal mining region of Alberta, learning about the historical copper belt through the Boundary country, gold and silver mining in the Kootenays, and visiting a large open-pit coal operation near Sparwood. The second trip went north visiting open pit copper mines and a combination open-pit and underground gold mine. Both trips resulted in samples and slides which are used during this topic.

British Columbia not only has a rich history of metal mining but coal has been important from the earliest days with mines on Vancouver Island playing a large part in the early development of this province. Relatively small scale coal mining occurred in the Nicola Valley and the Princeton area between the wars, and those mines in the Kootenays and Crows Nest supplied the coke for the various historic copper smelters. The Crows Nest area is currently the only region in British Columbia where large scale coal mining is taking place, though for a time recently coal was mined in the north-east Rockies at the new town of Tumbler Ridge, but that has now shut down as a result of reduced world prices and accessibility. British Columbia is an ongoing example of how supply, demand and other market forces impact on the mining industry.

It is also important to me to not forget the human costs of mining and here I stray from conventional geology texts by listing some of the worst coal mining disasters in Canada from both sides of the country, in a chart compiled from a number of sources. I point out to the students that it was not just the matter of the deaths but also the shear poverty into which the wives and children inevitable suffered with the loss of the family breadwinner, in days when there were not the supporting services that we take for granted today. Apart from the deaths there were the accidents leading to permanent injuries or loss of limbs, and there were also those miners debilitated from black lung disease so that they could no longer work.

Date	Location	Province	Deaths	Comments
1873/05/13	Westville, Pictou County	NS	60	Fire & Explosion
1885	McBean Mine, Pictou County	NS	13	Explosion
1887/05/03	Esplanade, Nanaimo, V.I.	BC	148	Explosion
1888/01/24	Wellington, Nanaimo, V.I.	BC	77	Explosion
1891	No. 1 Mine, Springhill	NS	125	Explosion
1901/02/15	Union Colliery, Cumberland, V.I.	BC	64	Explosion
1902/05/22	Coal Creek, Fernie, Kootenays	BC	128	Explosion
1910//12/09	Bellevue, Crowsnest Pass	AB	30	Explosion
1914/06/19	Hillcrest, Crowsnest Pass	AB	189	Explosion
1917	Coal Creek, Fernie, Kootenays	BC	34	Explosion
1930/08/15	Blakeburn, Princeton	BC	45	Explosion
1956/11/01	No. 4 Mine, Springhill	NS	39	Explosion, 88 rescued
1958/10/23	No. 2 Mine, Springhill	NS	75	Explosion
1967/04/03	North Palmer Mine, Michel	BC	15	Explosion
1996/06/05	Westray, Cape Breton	NS	26	Explosion

For the Activities component I have collected or acquired during the last four years large samples of most of the major minerals of Canada, samples of the production processes for copper such as the basic mineral, concentrate samples, crude metal and copper slag. In terms of the fossil fuels I have samples of the different types of coal, oil sands samples and oil bearing drill cores from Alberta. With these I have continued the process of developing hands-on interpretive activities.

For this topic and the topics on minerals and rocks, it is important that the teacher identify who their resources might be and to then learn to ask. The first day of classes I find out if anyone has a relative who is a geologist, or working in the mining or exploration industries, the people on my staff know that I am a collector and bring me old samples from their basements from long ago trips, or current gatherings from their summer holidays. During the spring someone left a terrific sample of chalcopyrite in my office mail box, and in spite of enquiries nobody ever owned up, even though I suggested that roses and dark chocolate work just as well for me. I always take any offerings as it is easy later on to either pass them on to another teacher or if they are absolutely no real use to throw them away, but it is so important with this subject to gather the resources and the bigger the army you have working for you the better your resource collection will become.

This chapter has focussed on three specific topics to further illustrate many of the issues that come up in the teaching of geology but are not so important in the other sciences. Resources are of prime importance and unlike the other sciences I can only purchase the very basic samples. If I am teaching physics and I need some new meters I can order them and know exactly what I am getting, similarly for chemistry I can order my materials and equipment from the supply companies, my only concern being that it is good value for money. If I order fossils from a catalogue I only know in general terms what I am ordering because this is an example in which it is important to know what one is purchasing since what is important to me as a geology educator is not that it is a museum quality specimen but rather is the fossil good enough for students to identify from keys.

For example I ordered a sample of the pelycepod Exogyra, which I had known from my previous school and my identification key charts as a fairly large shell. When the order arrived I had been given a cluster of three very tiny fossil shells that bore no relation to the key charts or my previous experience. The fossil was really no use to me in the way I wanted to use it - the students could not come close to identifying it as an Exogyra. I have since purchased from a local supplier a large Exogyra that can be readily keyed out by the students, more expensive but at least useful. If I go and collect my own fossils it can frequently require extensive research to properly identify the specimens. Since I use so much of my own materials then I am cognizant of the fact that as a professional I should build up a parallel and documented collection for the school because there is going to be a time when I shall move on or retire. The other science teachers do not have to be concerned about such issues as nearly all the materials they use belong to the school and will stay there.

In Chapters 4 and 5 I focussed on the general overview of the programme that has evolved, whereas in this chapter I focussed more on the Resource Guide development with examples of different kinds of writing that is focussed on learning, the development of hands-on activities, and the challenges behind acquiring resources. One can have a wide selection of resources but if the teacher does not know what they are or the context in which they arrived at the school, or has no stories to tell, then they are just mere artifacts that sit and collect dust.

7. The Future

Four years ago I walked into a new school to become the sole geology expert to teach Geology 12 out in a cramped and musty portable, physically cut off from my peers and with "twelve boxes of gravel and plastic fossils" as the principle resources the school could offer me. I did have a small personal collection of rocks, fossils, posters and 35 mm slides that I could also use. I was faced with students having a much greater variation in terms of prior learning than the other grade 12 science teachers and had to get all of them to the point that they had the potential to do their best on an externally imposed government exam.

As described in the earlier chapters, the teaching of grade 12 sciences has traditionally been a culture of mythic knowledge, of absoluteness, transmissive and regurgitive teaching, highly stylized writing, reader unfriendly texts, with little or no connection with the social and historical context of Canada. The students had very traditional expectations of both their role and the role of the teacher–the teacher was expected to give the knowledge so that they, the students, could regurgitate the right answer back on the test. Class activities were generally low level exercises in verification, again looking for right answers, but frequently were not considered to be really important because "they were not on the exam". This, for the first time in my career, was the culture with which I had become quite disillusioned, a culture I wanted to challenge right from the beginning with a new course and new curriculum.

As it turned out, being the "new kid on the block", who was also the only geology teacher, cast out into the "back forty" in a portable gave me the chance to develop my programme away from interference and pressures to conform. However, during the first exploratory year of this teaching I went through the same experiences as Mitchell (1997) when he observed "The students did not see any connection between better thinking and better test results." (p. 41). It would have been easy to return to conventionality and forget that I ever had a vision. Today, students come to my class knowing thattheir experiences will be somewhat different to those that thay may have had before, but who are much more willing to accept my mantra of learning

Before I could change to a more independent learner focussed teaching model I made myself thoroughly familiar with the prescribed curriculum and the available resources, and by the Christmas break of that first year I had focussed on eight aspects of the process that I would have to develop. Apart from the first point–I had to develop an overall learning framework based on the prescribed learning outcomes, the others are listed in no particular order.

1. Develop a more learner focussed topic matrix.
2. Assess and inventory the available text resources
3. Assess and inventory physical resources.
4. Develop storage and record keeping systems for the samples.
5. Assess and inventory visual resources such as slides, videos and cd's.
6. Introduce students to PEEL metacognitive strategies that focussed on multiple learning contexts
7. Introduce more decision making strategies for students.
8. Start developing hands-on activities for each topic.

Once these eight focuses had been identified the next task was to create an action plan that would give me some direction as to how I wanted to implement these various tasks, Appendix A.

However the action plan does not indicate that I have been engaged in two intertwined research projects during the last four years. The more obvious one has been the development of a multi-layered approach to learning in which, although I kept overall control as I am professionally accountable for delivering the geology curriculum in an effective and timely manner and was cognizant of an external exam at the end, I did hand much of the responsibility for student learning to the students themselves. The second research project was the geological and field research to both develop my Geology 12 Resource and Activity Guide, but also to build up my primary tools, my collection of samples. Consequently there are two reference lists supplied, one for the Resource and Activity Guide, Appendix I, and the traditional pedagogical reference list at the end of this narrative.

Some of these eight aspects I had identified were fairly easy to accomplish although somewhat time consuming to put into effect. Initial storage of small samples were organized into re-sealable plastic bags and stored in stackable cut down paper boxes. All the different types of resources were then listed in various data bases for easy access to the information. Over the course of the first couple of years specialized resources were stored in custom made compartmentalized boxes, both so that they would not bang against each other and be damaged but also as a simple method of inventory control ensuring that all the samples were returned at the end of class. Videos and the few compact discs that I had were reviewed for their potential usefulness for learning and for the most part were discarded–they were generally bland recitations of a great many facts that were not always correct.

The collection of hand-size resources to eliminate reliance on the tiny gravel chips would take time and energy and was a full three year project. During that first year I was able to purchase a selection of fossils representing most of the different phyla listed in the learning outcomes, but was not able to use them until the second year. Apart from my mining trip during the previous summer, I had the chance to visit southern Oregon collecting samples and slides of the Cascade volcanoes during the Spring Break of that first year, followed in the summer with the chance to spend over five weeks in Victoria, Australia with a week chasing volcanoes on the north island of New Zealand. Both trips brought a huge increase in samples, slides, posters and books. Since I started teaching Geology 12 my personal collection of 35 mm slides has tripled as has the shelf length of my own geology library at considerable expense but also considerable enjoyment to me.

During that first year time was primarily spent developing the conceptual ideas behind the hands-on activities that I wanted to create and because of a lack of resources only the initial stages of each were developed. By the end of the first year I had at least one activity outlined for each topic, but the second and third years saw a great expansion of both specimens and resources and the associated activities that derived from them.

Even though I had accepted the PEEL philosophy of developing metacognitive learners a number of years earlier, implementing some of these strategies took a great deal of time and patience during that first year or two starting with simple activities such as concept and mind-mapping as tools for making connections between learnings. Although the students were happy not to be writing stylized formal labs it took time for them to understand that a journal had to be well written and presentable to be useful for learning and review. The students accepted the topic overviews, Appendix E, as these did not constitute a threat in that they did not have to do anything with them, but were certainly uncomfortable at first at using the prior learning chart, Appendix F, until they began to understand that it was a tool for their own use if they were going to become more independent learners, and that it was not for me to mark. In the early years the students struggled to evaluate their own prior learning. I now own the PEEL CD-ROM and hope to use the information in it to exapand my repertoire os strategies. A number of other teachers have expressed an interest inthe PEEL process and it is my hope that we can formalize a working group in the school.

At this point in time after four years I am no longer an unknown quantity and even if Geology 12 is a student's first direct exposure to my approach to teaching, they come to class having heard that I am interested in learning, and although this class will be challenging and different from their earlier science experiences their marks will not suffer. However it is still a battle with the students who have not had me before for them to throw away their conceptions that the teacher's role is to just give them the right answers and all they have to do to pass is to correctly feed the right answers back to me. It takes at least to the end of the first Unit before most are reasonably on track in terms of taking responsibility for their own learning, accepting responsibility for completing their work within the time allowed, and understanding that because the multi-level process has built in collaboration and self checks that I am generally not going to mark their assignments for an academic mark except for specific subsections, but will always check it for completion on time. In other words, are the students doing the "job" in a proper and timely fashion. I no longer have students charging ahead to answer the questions or asking just for one book.

In terms of text resources, although Thompson et al. (1995) is no longer listed as an approved resource, for all its flaws I certainly cannot justify spending about $80.00 a book on replacement texts of just as questionable quality. Most of the heavy writing involved in developing the student Resource and Activity Guide was completed during the second and third years and from now on I only expect minor changes to the main text, generally in the form of new supplementary reading articles to keep us all up to date. The Activities will undergo constant refinement as I develop or come across new resources or new ways of helping students learn a concept. In terms of physical resources most that I need I have now obtained with the exception of slowly building up the large minerals collection during the next two years depending on budgets, and of course taking advantage of anything that serendipitously comes my way.

In my initial assessment of how to develop the Resource and Activity Guide my focus was on more reader friendly writing using strategies and techniques that would facilitate student learning. I was also cognizant of the Science Council of Canada's call for more social and historical context in Canadian science courses. My only assessments of the effectiveness of this guide are that I have to really work at getting the students to use their textbook and that during the last year, well over three quarters of my students wanted to take the guide home with them at the end of the year. In spite of traditional science teaching ignoring the social and historical contexts, I feel vindicated when Nowlan (2001) in the summary to his article on the connections humans have with the Earth stated

> "Humans are losing touch with the Earth. They tend to ignore the strong linkages between earth resources and the level of civilization they enjoy. They also tend to ignore the forces of earth processes, rendering themselves insensitive to natural processes and hazards. . . . It is critical that we place more of a social context on earth science, especially as it is communicated to the public. We (earth scientists) need to re-establish the connections between our well-being and the earth resources that make it possible. We also need to educate society about how earth processes affect our everyday life. By the same token, we also need to elaborate more of the social context of earth sciences to students of earth sciences." (p. 51)

I particularly like the last sentence in the context of my own teaching and writing and over the next few years intend to develop more of this social context into all facets of my teaching, not just Geology 12.

As the curriculum evolves in the future I would like the developers to become more aware of changes within the field and not keep topics just because they have always been there. It is bad enough working around resources that continue to perpetuate misunderstandings, but in my mind it is unforgivable when the prescribed curriculum does the same. Curriculum developers should be up to date in their field and should not still be talking about biological weathering for example. In a more recent development I will have to deal with the issues recently raised by Jones (2001) when in an article about earthquakes and their prediction she stated:

> This idea (earthquake control) was particularly appealing in the late 1960's, when geologists were beginning to suspect that it was impossible to predict quakes. . . . Over the years, people have tested a thousand ways of predicting quakes, from measuring radon concentrations in well water to watching animals for signs of bizarre behaviour. But nothing has proved reliable." (p.34)

Come next year I will still be expected to teach learning outcome L6 in the current Geology 12 IRP in which students are instructed to "evaluate various methods of earthquake prediction (e.g., dilitancy data, seismic gap, animal behaviour)". (p. A-20) Even though I will have to teach this outcome to my students in anticipation of a possible question on their external exam I will also tell them that recent evidence suggests that none of this works - but "You still have to know it for the test."

I have been concerned for a number of years that high school teachers of academic subjects rarely work or research in their teaching fields. The so-called lower status teachers are all expected to work in their field, it is considered to be an advantage for an art teacher to put on shows of his or her work, similarly with the pottery or photography teacher. The drama and band teachers are encouraged to not just put on external programmes but frequently work in their chosen fields outside of the school setting. Developing this course has given me, an academic teacher, a similar sort of status - I do geology by getting out into the field and then sharing those samples, slides and stories with the students and this is certainly appreciated by my students. I would probably say that being so well accepted by the students has had a significant influence on my learner focussed approach, that challenges all their traditional belief systems. As an example of a lifelong learner I find that the line between learning for me and learning for my students, the boundaries between work and play, becomes quite blurred at times and as long as I am still enjoying my life I shall continue. I do get a personal reward at being both a pedagogical and a science researcher.

In the process of putting the responsibility for learning onto the student, I have freed up a lot of time that I had previously spent doing mundane routine work or hoop jumping because that is what is expected. Within a few weeks, the students come into class, look at the weekly calendar and get on with the tasks they need to complete. I have reduced much of the mundane marking for marks sake, the sort of marks that end up contributing to a student's academic mark, but really only reflect work habits. I have become much more critical of my own marking practices ensuring that only marks that truly reflect demonstrated learning by that student contribute to his/her academic grade. Any other marking that primarily reflects work habits is now separated out with the benefit that my work habits marks are much more defensible. By not spending time always going over and reviewing every question, but rather checking for completeness and then, after signing their work off, making the students responsible for their corrections gives me further time to spend on monitoring student learning, continuing research and resource development.

I have had the opportunity to develop a whole new learner focussed approach to teaching Geology 12, and after seeing it's success at that level my work over the next few years will move towards bringing these teaching approaches to my earlier grades. As Baird (1992) indicated education research is so markedly different from science research in that in education we cannot isolate any of the variables that contribute to good learning. The best one can do is todevelop a matrix of frameworks through which one hopes to improve student learning for there is no single magic bullet in the endless drive to improve learning. These frameworks must allow for a diversity of learning styles in a variable population living in a complex of external influences. I feel that the approach described here has been extremely successful through the development and implementation of the multi-layered learning model.

At the beginning when I was developing the multi-level model I was concerned about assessment of the programme and decided that I had no valid assessment tool. If I was interested in measuring the effectiveness of this multi-level approach on long term learning, on the ability of the learners to take more responsibility for their learning, to move my learners more in the direction of life-long learning, all major components of my early goals then I would have to track my students down and personally interview each of them after a period of two years and then five years. However, if my assessment of the model is indicated by the number of graduated students who return to visit me providing further samples which they can invariably correctly identify, or relate the geological sites and features that they saw on a trip, or by the many comments that for the first time in their life students feel that they have really learned something, or when a student on a basketball tour through Nevada asks to stop the tour bus so that she can collect a sample of red sandstone for her geology teacher, or the number who insist on keeping the resource package that I have developed for them, then the model is a resounding success.

In terms of the impact of change, I have noticed that some of my science peers are making changes to their practice. Some are now posting their answers on the wall, others are not afraid to give the students the learning outcomes, and some are even starting to think in terms of strategies for learning, at least with their junior grades or their grade 11 classes. Change is slow but as the literature so clearly indicates most successfully occurs when it is modelled not imposed.

So where to now? I am out of the worst of the swamp though not on the rigidity of the high ground, perhaps the ever shifting sand of the beach. I want to continue working with the multi-layered model and implement the processes more fully in all my other classes. It has confirmed for me that students are quite capable of taking more control over their own learning and in my experience become more powerful learners as a result of that process. The feedback I am receiving from both students and parents as a result of trying some of these processes during the earlier grades indicates that they work. With the continuing increase in enrollment in Geology 12 more classes and more teachers will be needed. In my experience this is a wonderful course for challenging tradition and focussing on teaching for learning, and I hope that some of those teachers might read this thesis and gain some new insights in terms of their own teaching. What I have described is a combination of concepts and ideas for others to take away, stir around in their minds and to then repackage for their own operational context. In terms of grander visions, I would like to see a really good geology text being developed in Canada, but a text that is much more reader friendly than current texts, is focussed on Canada but also brings in the rest of the world, and has a clearly defined philosophy towards improved learning and understanding not just a glorified litany of definitions for rote memorization, and I would like to be part of that process.

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Appendix A

Geology 12 - Timeline For Change

Year 1	Year 2	Year 3	Year 4
Develop topic matrix.	Monitor topic matrix.	→	→
Assess/ inventory text resources. Start writing supplementary readings for local, & Canadian/ World content.	Research suitable journal articles to reinforce Canada's role in the geology world. Evaluate and expand initial writings; ensure LO's covered.	Field test use of journal articles. Refine initial resources book.	Keep using journal articles. Slowly add to collection. Continue refining resource book.
Assess & inventory physical resources & samples. Identify major resource gaps. Develop data bases for sample and resource records.	Order basic fossils, organize secure storage & inventory control system. Do research and field work to start collecting more rock and specialty samples. Make microsamples.	Start ordering large mineral samples identify gaps and add to fossils. Continue research into field work for rock, fossil and specialty samples.	Continue ordering large mineral samplesuntil set complete Continue research into field work for rock, fossil and specialty samples.
Develop storage system for samples, to maximize space but keeping easy access.	Expand storage, continue to use modified cardboard paper boxes.	Move to plastic bins with lids for reducing loads and better stacking. Compartmentalize cut down paper boxes for storing valuable specimens.	Continue with plastic bins. Standardize bins to two sizes for easy storage.
Assess and inventory visual resources slides, videos.	Do field work to start building slide and picture resources.	Continue field work building slide and picture resources.	→
Introduce to PEEL metacognitive strategies that also focussed on multiple contexts for learning.	Continue with and add to PEEL strategies where appropriate.	Continue with and add to PEEL strategies where appropriate.	→
Introduce more decision making strategies for students.	Introduce student self-monitoring charts. Introduce multi-layer learning model.	Continue self-monitoring system. Refine learning model.	→ Continue to refine learning model.
Start developing hands-on activities.	Assess effectiveness of initial hands on activities, modify. Continue new development as resources increase.	Develop further hands-on activities to fill in major gaps. Aim for minimum of one activity per topic.	Continue to add to hands-on activities.

Appendix B

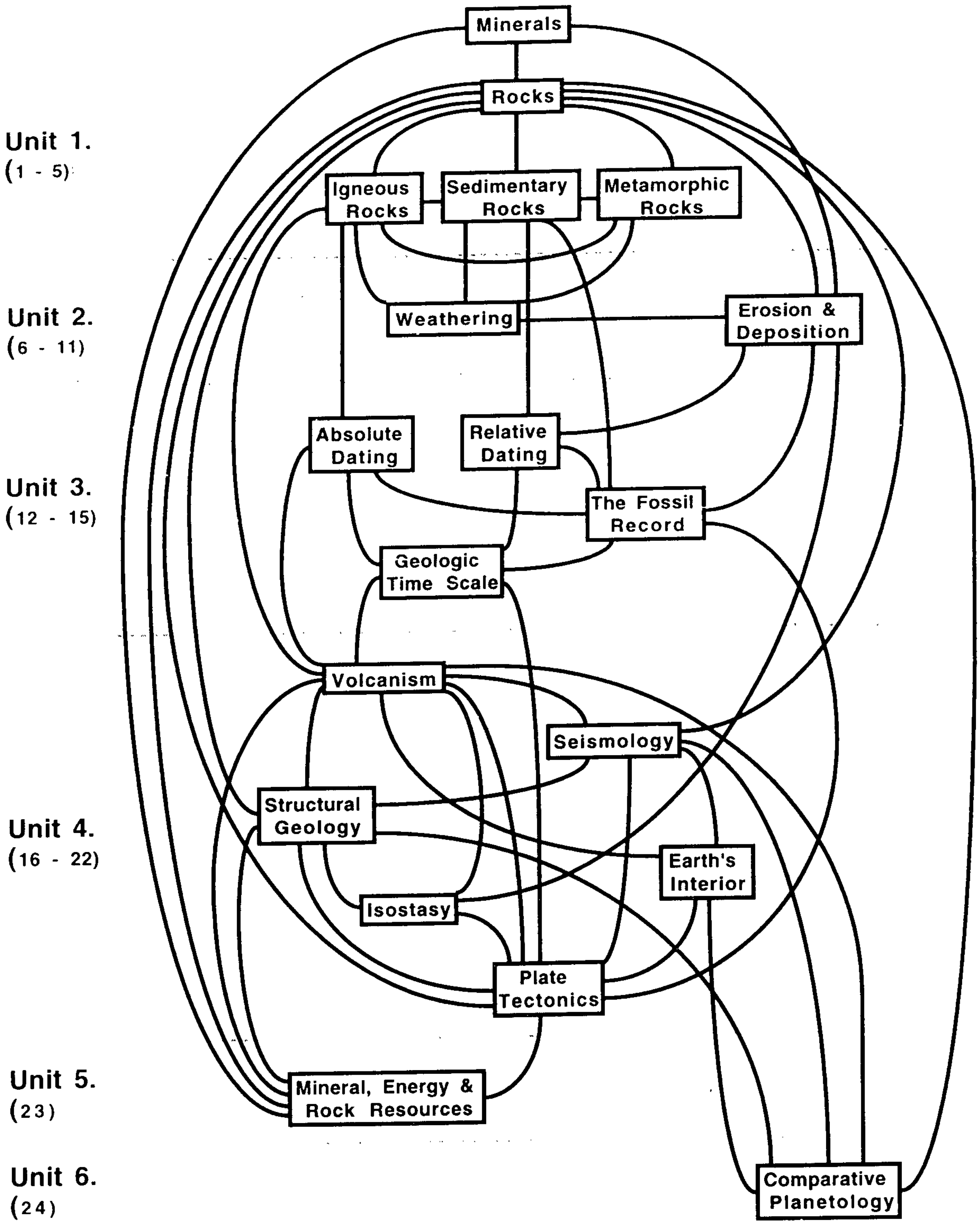
Geology 12 Provincial Curriculum Topics
(pp A13 - A23)

The following chart indicates the Unit and Topic sequence for Geology 12, together with the general text references. In the Text References column, the first number indicates the chapter, the numbers in brackets the relevant topic sections within that chapter. As well as the regular textbook, you will be issued a supplementary Text Resource Package and an Activity/Questions Package.

Teaching Sequence		Curriculum Topic	Text References "Earth Past & Present"
Earth Materials			
1	A -	Introduction to Geology	1 (1-2)
2	B -	Minerals	2 (1-7).
3	C -	Igneous Rocks & Processes	3 (2-4).
4	D -	Sedimentary Rocks & Processes	3 (5-7).
5	E -	Metamorphic Rocks & Processes	3 (8,9); 3 (1).
Surficial Processes			
6	P -	Weathering, Erosion & Deposition	9 (1-7).
7	Q -	Running Water	10 (1-9).
8	R -	Glaciers	12 (1-5).
9	S -	Ground Water	11 (1-7).
10	Q -	Waves and Coastlines	14 (1-10).
11	Q -	Wind Effects	13 (3).
Time & The Fossil Record			
12	G -	Relative Dating	15 (1,2).
13	H -	The Fossil Record	(selected topics)17 to 21
14	I -	Absolute Dating	15 (3,4).
15	J -	Geologic Time Scale	1 (3); 15 (3,4).
Internal Processes & Structures			
16	C -	Vulcanism	6 (1-7); 11 (6,7).
17	O -	Strutural Geology	8 (3).
18	M -	Isostasy	4 (4).
19	L -	Seismology	5 (1-6); 8 (3).
20	N -	Earth's Interior	1 (1,6); 5 (7).
21	K -	Plate Tectonics	4 (1-11); 7 (1-7); 8 (1,2,4-6).
22	-	Tectonics & B. C.	7 (6); 8 (4,5); HO's.
Resources			
23	F -	Mineral, Rock & Energy Resources	22 (1-8).
Comparative Planetology			
24	T -	Comparative Planetology	1(4); 23 (1-10).

Appendix C

Geology 12 - Major Learning Connections



Appendix D

Geology 12 Assignment Topics

Topic No. **Topic Title**

Earth Materials

Topic No.	Topic Title	Assigned	Due	Handed In
1	Introduction to Geology			
2	Minerals			
3	Igneous Rocks & Processes			
4	Sedimentary Rocks & Processes			
5	Metamorphic Rocks & Processes			

Surficial Processes

6	Weathering, Erosion & Deposition			
7	Running Water			
8	Glaciers			
9	Ground Water			
10/11	Waves and Coastlines/Wind Effects			

Time & The Fossil Record

12	Relative Dating			
13	The Fossil Record			
14	Absolute Dating			
15	Geologic Time Scale			

Internal Processes & Structures

16	Vulcanism			
17/18	Strutural Geology/Isostasy			
19/20	Seismology/Earth's Interior			
21	Plate Tectonics			
22	Tectonics & B. C.			

Resources

23	Mineral, Rock & Energy Resources			

Comparative Planetology

24	Comparative Planetology			

Appendix E1

Topic 3 - Igneous Rocks & Processes (C)

Provincial Learning Outcomes (Geol. 12 IRP p. A-15)

It is expected that students will:

A3 differentiate between rocks and minerals

C1 describe and demonstrate factors affecting cooling rate and crystal size

C2 relate texture to rate of crystallization for extrusive (volcanic) and intrusive (plutonic) igneous rocks

C3 identify and classify igneous rocks according to their texture (coarse or fine grained, vesicular, glassy, fragmental-pyroclastic) and composition (felsic, intermediate, mafic)

C4 describe the features of and describe the following igneous rocks - granite, diorite, gabbro, peridotite (ultramafic), andesite, tuff, rhyolite, basalt, volcanic breccia, obsidian, pegmatite, pumice, porphyry

C5 describe and explain the order of crystallization of minerals from a magma (Bowen's reaction series).

Main References

Earth Past and Present. Chapt. 2, Sect. 2.6, pp.33 - 38
Chapt. 3, Sect. 3.1-3.4, pp 42-49;
H/O #3a Classification of Rocks
H/O #3b Igneous Rocks (C)
Colour Index Chart
Properties of Common Igneous Rocks
Bowen's Reaction Series Chart
Geological Survey of Canada Rocks Poster
Geological Survey of Canada Geomap Vancouver Poster
Samples of Igneous Rocks

Useful Web Sites for Topic 3 - Igneous Rocks

UBC- Geology 202 < http://www.science.ubc.ca/~geol202/ >

Appendix E2

Topic 16 - Vulcanism (C)

Provincial Learning Outcomes (Geol. 12 IRP p. A-15)

It is expected that students will:

C4 describe the features of and describe the following volcanic rocks: rhyolite, dacite, andesite, basalt, pegmatite, porphyry, obsidian, pumice, tuff, volcanic breccia, scoria.

C5 describe and explain the order of crystallization of minerals from a magma (Bowen's reaction series).

C6 distinguish among the following volcanic features:
shield volcanoes, cinder cones, composite volcanoes, volcanic domes, lava plateaus, rift / fissure eruptions, caldera.

C7 distinguish among the following types of lava by their composition and flow behaviours, and identify or predict the rock or feature formed when the lava cools:-
ash/pyroclastic flows or nuée ardente, pillow lava, aa or pahoehoe lavas.

C8 identify and describe batholiths, sills, dikes, columnar jointing, xenoliths, stocks and plutons

C9 compare and contrast contact, regiona,l and hydrothermal metamorphism, relating them to volcanic or magma activity; describe changes that occur in the country rock and in the intrusion at a contact.

C10 identify and describe a number of volcanic hazards.

Review:-

Earth Past and Present. Chapt. 3, Sect. 3.2-3.5, pp 43-53.
H/O #3(C) Igneous Rocks.
H/O's Igneous Rocks & Bowen's Reaction Series.
Earth Past and Present. Chapt. 3, Sect. 3.9, pp 64-68;
H/O #5 Metamorphic Rocks

Main References:-

Earth Past and Present. Chapt. 6, Sect. 6.1-6.7; pp 124 - 148.
Chapt. 11, Sect. 11.6-11.7, pp 258 - 261.
H/O #16 Volcanoes in Action.
Hickson, Catherine (1990) Can it happen here? Geos. 19 (1) pp. 3-7
Monitoring volcanoes and forecasting eruptions in Monroe, J. S. & Wicander, R. (1992). Physical Geology. pp. 94-5
Nishg'a Memorial Lava Bed Park(1992) pp. 3-8. B.C. Parks
Canadian Geographic (1993) (May/June) p.28
Miscellaneous Handouts
Videos - Fire Mountain; Cascadia
Volcanoes Slides
Volcanic rock samples

Useful Web Sites for the Topic 16 - Volcanoes

Canadian Volcanoes and Volcanics
< http://vulcan.wr.usgs.gov/Volcanoes/Canada/framework.html >

GeoMap Vancouver < http://sts.gsc.nrcan.gc.ca/page1/urban/geomap >

Natural Hazards (Canada) < http://cgdi.gc.ca/ccatlas/hazardnet/a_contents/content.htm

Volcanoes < http://pubs.usgs.gov/gip/volc/ >

Volcanoes of the US < http://pubs.usgs.gov/gip/volcus/ >

Volcano World < http://volcano.und.novak.edu/ >

Smithsonian Institution - Global Volcanism Program
< http://www.volcano.si.edu/gvp/ >

MTU Volcanoes Page (Michigan Technical University)
< http://www.geo.mtu.edu/volcanoes/ >

Cascade Volcano Observatory < http://vulcan.wr.usgs.gov.home.html >

Alaska Volcano Observatory < http://www.avo.alaska.edu/ >

Hawaii Volcano Observatory < http://hvo.wr.usgs.gov/ >

Deschutes National Forest < http://www.fs.fed.us/r6/dechutes/ >

Gifford Pinchot National Forest < http://www.fs.fed.us/outernet/gpnf/index.html >

Volcanic and Seismic Hazards on the Island of Hawaii
< http://pubs.usgs.gov/gip/hazards/ >

ManAgainst Volcano: The Eruption on Heimaey, Vestmannaeyjar, Iceland
< http://pubs.usgs.gov/gip/heimaey/ >

Monitoring Active Volcanoes < http://pubs.usgs.gov/gip/monitor/ >

Appendix E3

Topic 23 - Mineral, Rock and Energy Resources (F)

Provincial Learning Outcomes (Geol. 12 IRP p. A-17)

It is expected that students will:

A3 differentiate between rocks and minerals

F1 explain how hydrothermal activity can produce ore bodies

F2 describe how simple geochemical or geophysical data can be used to locate mineral, rock, or petroleum deposits

F3 describe the uses of mineral, rock, and energy resources of major economic importance in British Columbia, including:
- chalcopyrite, galena, gold, sphalerite, molybdenite, gypsum, limestone
- construction materials, coal, oil and gas

F4 deduce the origin of an ore body or a mineral or petroleum resource from data and geological descriptions of the deposit

F5 describe the sequence of events through which oil and natural gas are believed to form

F6 explain how a variety of factors (e.g. price, concentration, accessibility, size, and environmental considerations) determine whether or not it is economically feasible to extract a given occurrence of a mineral, rock, or energy resource

F7 explain the role of permeability and porosity in creating oil and gas reservoirs and traps

F8 describe the sequence of stages in the formation of different grades of coal

Main References:-

Earth Past and Present. Chapt. 22, Sect. 22.1, 3, 5-8; pp 613 - 637.
Chapt. 3, Sect. 3.9; pp 65/67.
Chapt. 7, Sect. 7.4; pp 156 - 157.

Jonsson, R. (1985). Coal Sources 2 (2) pp 1-9. Vancouver, B. C.: B. C. Hydro
Cominco Ltd. Fact Sheet - Making lead and zinc.
H/O #23 Mineral Resources
H/O #2 Minerals, particularly the data base
Mining Slides

Useful Web Sites for Topics 23 - Mineral, Rock and Energy Resources

British Columbia & Yukon Chamber of Mines
< http://www.bc-mining-house.com/ >

British Columbia Ministry of Energy and Mines
< http://www.en.gov.bc.ca/ >

Canadian Mining Facts < http://www.nrcan.gc.ca/mms/efab/mmsd/facts/ >

Mining Industry Links < http://www.georad.com/anglais/info/liens_min_ang.htm >

Infomine Canada < http://www.infomine.com/countries/canada.html >

Coal Association of Canada < http://www.coal.ca/index.html >

Crowsnest Coal < http://www.crowsnest.bc.ca/coal.html >

Silver Lead Zinc Mining and Cominco
< http://www.crowsnest.bc.ca/mining01.html >

History of Coal Mining in Nova Scotia
< http://eagle.uccb.ns.ca/mining/ >

Environmental Mining Council of British Columbia
< http://emcbc.miningwatch.org/Content.htm >

Friends of the Earth < http://www.foecanada.org/campaign/mining/bigpictu.htm >

Appendix F

3 - IGNEOUS ROCKS - Knowledge/Skill Inventory

For the study of igneous rocks, it is necessary to be able to understand how the rock's formation is related to the crystal structure and properties.

Read each of the following statements carefully, and put a checkmark in the box that **BEST** reflects your present knowledge or skill ability for that statement. Use the chart as a self check as you proceed through this topic.

KNOWLEDGE or SKILL	Must learn or Practice	Not Sure	Know / Can Do	Relearn
1. Know the difference between an intrusive and extrusive rock.				
2. Know the difference between, and origin of, a phaneritic, aphanitic, and porphyritic crystal structure.				
3. Can identify the different minerals in common plutonic rocks.				
4. Can relate a colour index chart to the proportions of light and dark minerals in a plutonic rock.				
5. Know the differences in chemical composition between sialic/felsic and mafic igneous rocks				
6. Can identify the following plutonic (intrusive) rocks - granite, diorite, gabbro and peridotite				
7. Can identify the following volcanic (extrusive) rocks - rhyolite, dacite, andesite and basalt.				
8. Can relate the silicon content of rhyolite, dacite, andesite and basalt to the viscosity of the molten rock				
9. Can identify the following volcanic rocks - porphyry, pumice, obsidian, tuff, scoria and volcanic breccia				
10. Can interpret a standard composition diagram for igneous rocks				
11. Can explain the order of crystallization of minerals from a magma				

Appendix G

Geology 12 - RESOURCE AND ACTIVITY GUIDE

Table of Contents

Appendix H

GEOLOGY 12 SUPPLEMENTARY READINGS BY TOPIC

Topic 1 - SURFACE FEATURES OF THE EARTH

The Geological Survey of Canada. (1992). Geos 21(1), 2-3.

Topic 6b MASS WASTING

Gadd, N. & Peddle, T. (1984). Landslide. Geos 13(3), 18-21

Topic 8 - GLACIAL EROSION

Watts, S. (1984). Highly weathered bedrock terrain - an enigma in Arctic Canada. Geos 13(3), 7-9.

Clague, John. (1987). Catastrophic outburst floods. Geos 16(2), 18-21

Topic 9 - GROUND WATER

Groundwater - our hidden treasure in B. C. Ministry of the Environment/ Environment Canada (1993). State of the environment report for British Columbia. (29-32). Author: Victoria/Ottawa

Topic 13 - THE FOSSIL RECORD

Morris, S. C. & Whittington, H. B. (1986). The Burgess Shale. Geos. 13(1), 6, 8-9.

Mungall, C. & Donnelly, V. (1986). The quarries continue to yield their mysteries. Geos. 15(1), 7, 10-11.

Jerzykiewicz, T. (1989). 1988 Sino-Canadian dinosaur project expedition successful in Inner Mongolia. Geos. 18(4), 1-6.

Wilford, J. N. (1998, February 5). Chinese fossils reveal earliest animal forms. Vancouver Sun. pp. A1, A2.

Topic 14 - ABSOLUTE DATING

McNeely, R. (1988). Radiocarbon dating laboratory. Geos 17(2), 10-12

Topic 16 - VULCANISM

Hickson, Catherine (1990). Can it happen here? Geos. 19 (1), 3-7

Morgan, A. V. (2000). The Eldfell eruption, Heimay, Iceland: A 25-year retrospective. Geoscience Canada. 27 (1), 11-18

Topics 17/18 - ISOSTASY/STRUCTURAL GEOLOGY

California Department of Mines and Geology Notes #35. Geomorphic provinces and some principal faults of California

Topics 19/20 - SEISMOLOGY /EARTH'S INTERIOR

California Department of Mines and Geology Note #23.(1972). How earthquakes are measured

Marshall, J. (1985). Tsunami: The dreaded harbour wave. Geos 14(4),14-16.

Hume, S. (1998, June 6). Another quake, another reminder. Vancouver Sun. p. D4.

Michael, A., Reasenberg, P., Stauffer, P. H., and Hendley II, J. W. (1996, April 3). Quake forecasting –an emerging capability [Online]. USGS.Available:- http://quake.wr.usgs.gov/QUAKES/FactSheets/QuakeForecasts/ [1998, April 2]

Topics 21/22 - Plate Tectonics/Tectonics & British Columbia

Marshall, J. (1985). Lithoprobe maps subduction zone. Geos 14(3), 12-15

Riddihough, R. (1992). Seafloor spreading and Canada. Geos 21 (1), 8-9

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Monger, J. W. H. (1990). Continental-ocean interactions built Vancouver's foundations. Geos 19(4), 7-13

Hyndman, R. D., (1995). Giant earthquakesof the Pacific Northwest. Scientific American. (Dec.), 68-75.

Topic 23 - MINERAL, ROCK AND ENERGY RESOURCES

Jonsson, R. (1985). Coal Sources 2 (2), 1-9. Vancouver, BC: B. C. Hydro

Cominco Ltd. Fact Sheet - Making lead and zinc.

Topic 24 - COMPARATIVE PLANETOLOGY

Taylor, Jeffrey (1997). The Moon, gateway to the Solar System. In Martel, L. M. V. (Ed.) Exploring the Moon. NASA 1-6

Greeley, Ron. (1977). Photogeologic mapping of planetary surfaces. Santa Clara, CA: NASA Ames Research Centre.

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California Department of Mines and Geology Notes #35. Geomorphic provinces and some principal faults of California

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Coates, J. A. (1974). Bulletin 238 Geology of the Manning Park area, British Columbia. Ottawa: Geological Survey of Canada.

Decker, R. and Decker, B. (1981). Volcanoes. San Francisco, CA: W. H. Freeman and Company.

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Appendix J

Topic 6a - Weathering Samples

1. Rusted steel bolts and cable from Sechelt beach. Cable has more completely rusted as very little residual magnetism left - attacked more readily at the contact zone between the individual wires. The bolt is more solid therefore rusting can only proceed from the outer surface and inside still steel.

2. Rusting on metamorphic rock, Woodside Mtn., Agassiz. Rust/limonite, $Fe_2O_3 \cdot 3H_2O$, has a greater volume than pure iron therefore where it forms in iron rich fractured rock the rust tends to further separate the individual pieces making them more susceptible to further processes such as ice wedging and gravity.

3. a) - granite, unweathered
   b) - granite weathered and crumbly.

4. a) - Rounded river rocks, Gold Creek, Maple Ridge
   b) - Broken diorite, bottom of talus slope, Hwy 7, Haig (between Agassiz and Hope)
   c) - Broken granite, bottom of talus slope, Widgeon Creek Rd., Harrison Mills
   d) - Broken metamorphic rock, bottom of talus slope, Woodside Mtn., W. Agassiz
   e) - Rounded beach pebbles, Rosario Beach, Deception Pass State Park, Wash'n

5. 3 specs. - Rounded river rocks with later chemical pitting, Hazlem Creek, S. Nanaimo, V.I.

6. a-c) chemically weathered rounded river rock (gabbro - grey calcic plagioclase is weathering out more readily than the dark ferromagnesium minerals), broken into three sections. [Both #5 and #6 show combination effects of physical (abrasive rounding) and chemical (pitting) weathering.]

7. 2 specs. - Copper (II) carbonate only & native copper plus copper (II) carbonate & chalcopyrite

8. 3 specs. - showing progression of chemical weathering from outside in.

9. Quartz with extensive rusting and copper (II) carbonate.

10. Rusting of vesicular basalt, Newberry basalt flow, Lava Butte, S. Bend, Oregon. (700 000 a)

11. River eroded vesicular basalt with small pebbles in vesicules.

12. Limestone pitted from chemical solution, Florida Everglades

13. Unweathered and weathered samples of volcanic rock, Tertiary age basalt, from Hwy. 7, Whonnock. The weathered sample shows "onion peel" weathering

14. Part of a chemically weathered rounded river boulder (gabbro - grey calcic plagioclase is weathering out more readily than the matrix of dark ferromagnesium minerals) from Blue Mountain glacial till, Maple Ridge. Very similar surface and composition to #6.

15. This is a sample of shale collected by the Dempster Highway in the mountains of the Yukon. The most likely form of weathering acting on this shale is freeze-thaw.

Appendix K

Topic 3b - Igneous Rocks - Key Words/Phrases

Magma v Lava

Plutonic /Intrusive - underground

Phaneritic - large visible crystals

Volcanic / Extrusive - surface

Aphanitic - microscopic crystals

Sialic / Felsic / Silicic - Acidic, high viscosity -does not flow

Mafic - Basic, lower viscosity - flows easily, Ultramafic

Colour, Colour Index -indicates mineral content

Plutonic - Granite, Syenite, Tonalite, Diorite, Gabbro,

Peridotite, Pegmatite

Volcanic - Rhyolite, Dacite, Andesite, Basalt,

Porphyry, Obsidian, Pumice, Tuff, Welded Tuff, Volcanic

Breccia, Scoria

Vesicles - gas holes, Glassy

Bowen's Reaction Series

Appendix L

Geology 12 - Text Correlations

Topic No.	Topic Title	Thompson (1995)	Montg'y (1987)	M & D (1997)	M & W (1998)
Earth Materials					
1	Introduction to Geology	1	1	1	1
2	Minerals	2	2	2	2
3	Igneous Rocks & Processes	3	3	3	3
4	Sedimentary Rocks & Processes	3	4	6	6
5	Metamorphic Rocks & Processes	3	5	7	7
Surficial Processes					
6	Weathering, Erosion & Deposition	9	18, 19	5, 16	5, 14
7	Running Water	10	13	14	15
8	Glaciers	12	16	18	17
9	Ground Water	11	14	15	16
10/11	Waves and Coastlines/Wind Effects	14, 13	15, 17	13, 17	19, 18
Time & The Fossil Record					
12	Relative Dating	15	6	8	8
13	The Fossil Record	16	6	8, 19	
14	Absolute Dating	15	6	8	8
15	Geologic Time Scale	1, 15	6	8, 19	8
Internal Processes & Structures					
16	Vulcanism	6, 11	9	4	3, 4
17/18	Strutural Geology/Isostasy	8, 4	11	11	13
19/20	Seismology/Earth's Interior	1, 5, 8	8, 10	10	9, 10
21	Plate Tectonics	4, 7, 8	7	9	12
22	Tectonics & B. C.				
Resources					
23	Mineral, Rock & Energy Resources	22	20, 21	27	Scattered
Comparative Planetology					
24	Comparative Planetology	1, 23	1, 22	1	1, 20

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