Science and Mathematics Education Centre

Students' Understanding of Evidence in Science through Studying Paradoxes and the Principle of Falsification

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Declaration

This thesis does not contain material accepted, in any university, for the award of any other degree or diploma. To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgement has been made.

Signature:

Date: 5th July, 2014

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To my students, past and present, without whom I would not have written this thesis, particularly those students described admirably by the writer Jorge Luis Borges in his book *Labyrinths* which I paraphrase.

> …although I could expect nothing from those students who passively accepted my doctrines, I could of those who, at times, would venture a reasonable contradiction. (Borges, 1964)

To my fellow doctoral and masters students, the members of the aPIERon Academy, I thank you for your comradeship and engaging conversations.

Contents

Abstract

This thesis explores how students of science can come to understanding relationships between evidence in science, theory and logic in ways that enhance their capacity to use the language of science and logic, argue logically, and deduce outcomes and consequences intelligently from theories and evidences. I develop the role of the study of paradox as a teaching practice through day to day conversations between the students and the teacher-researcher. Particularly, I seek to ascertain the role that this type of study offers the development of students' evidentiary logic within the field of science and I question whether studying paradoxes can enhance students' capacity to articulate their understandings. I aim to develop a frame of understanding which might assist teachers to honour the innocence of students' logic, challenge it, and expand it further, beyond inherited, memic assumptions. This thesis opens an area of great significance for teachers of science and the logic of scientific discovery and implies the need for emphasis on exposing students to formal, abstract logic for the purpose of generating congruence between students' conceptions of scientific theory and evidence and their verbal and written articulations during classroom conversations and study. The thesis acknowledges the work of Sir Karl Popper, particularly *The Logic of Scientific Discovery* and *Conjectures and Refutations* for the questions and deliberations I explore.

Chapter 1 – Theseus' Journey

The Story of Theseus

In *A Midsummer Night's Dream*, William Shakespeare (edition circa 1920) portrays the legendary Greek hero Theseus as a man possessed of mature and balanced impartiality. Theseus' rationalism is a great asset to him in his role as statesman in Greek legend. Shakespeare illuminates Theseus against the blackest of black Fairy King Oberon. Yet in the finale of *A Midsummer Night's Dream*, the limitation of Theseus' rationalism is his heartless lack of sympathy and compassion for those whom he considers to be irrational.

Theseus is the son of Aegeus, the King of Athens, and Aethra, the Princess of Troezen. When he is of age Aethra sends Theseus from Troezen to Athens. There he finds his father bewitched and married to the sorceress Medea. Medea attempts to poison Theseus.

Shortly thereafter, the Sea God Poseidon (often confused in Greek mythology with Aegeus possibly because of the link with the name of the Aegean Sea) sends King Minos of Crete a snow-white bull. When Minos succumbs to the bull's beauty and fails to have it sacrificed, which was after all Poseidon's intended purpose for the gift of a sacrificial beast, Poseidon casts a spell on Minos' wife Pasiphae to make her fall in love with the magnificent white bull. The Minotaur, with the body of a man and the head of a bull, is born from Pasiphae's lust for Poseidon's gift. Shame-faced at the birth of Pasiphae's illegitimate and monstrous infant, Minos conceals the Minotaur in his labyrinth on Crete. The Athenians then kill Androgeos, the son of King Minos, and as a consequence Minos demands an extreme form of restitution. Until the arrival of our hero Theseus, the Athenians send seven Athenian boys and seven girls to their doom every nine years in the labyrinth of the Minotaur.

By the time the third group are required to be sacrificed young Theseus volunteers, with the intention of killing the Cretan Minotaur, once again returning heroically to Athens. Theseus' experience on his earlier journey from

Troezen to Athens had seen him slay many villains including Sinis, Sciron and Procrustes—his confidence had grown.

Ariadne, the Princess of Crete and the legitimate daughter of Minos and Pasiphae, falls in love with Theseus and gives him a string of jewels, the cord of Theseus, to light his pathway so that he can escape the inescapable Cretan labyrinth after slaying her half-brother the Minotaur.

The story ends rather ironically—perhaps it could be said *paradoxically* after Aegeus commits suicide because he believes, falsely, that his beloved son Theseus was killed in the labyrinth because Theseus' ship's sail remained black on the return journey and was not exchanged for a white sail—the agreed signal of a successful mission.

Upon his return, Theseus resoundingly–coldly–rejects Ariadne in order to secure a political alliance Theseus marries Hippolyte.

The Theseus Metaphor

Theseus' journey, the labyrinth, and the character of Theseus act as metaphors to shed light on this thesis and illustrate many perplexing consequences of studying paradoxes. It is paradoxical that rationalism can be both an asset and a liability when rational analyses of paradoxes lead to ambiguity. The lure of rationalism, like Theseus, bewitched me.

'Labyrinth' is one of many words used to illustrate the nature of paradox in this thesis. In future chapters, I use 'labyrinth' as a metaphor because finding one's way in a maze, whether in reality or in some abstract sense, is an experience common to many people. Although, for an unwary person it is easy to become disoriented in a labyrinth and feel lost, I discovered a trick when finding my way through a labyrinth—simply keep one hand pressed against either the left or right wall and walk, and even with my eyes closed I would find it possible to discover both the target within the labyrinth and, more importantly, the way out. If I am truthful the story of my labyrinthine journey must contain the many meandering side passages and frustrating blind alleys and not presuppose, as if the journey was a direct path from planning to destination. As a rational empiricist, I believe what you can know is derived only from your senses. I, as a logically constrained person, desire very much to dispense with my meanderings, but then again, my journey does not follow a direct route and to maintain its integrity the inclusion of blind alleys feels mandatory. Many of my anecdotes may portray an illusion of irrelevance, but, like the story of Sir John Mandeville (Milton, 2001) referred to later, my story is all the more convincing and real because of the inclusion of the many stories I will explore. Comparable to Mandeville's stories, many are utterly mindboggling yet at the same time they are nevertheless truthful. Sir John Mandeville's use of parable and puzzle stirred the imagination of his readers. I hope in some way to do the same.

In order to find my way in the labyrinth I created, instead of pressing my hand against some *concrete* wall, I pressed my mind against the *abstract* writing of certain authors. I would invite my readers to press their own minds against the authors, particularly Alfred Ayer, Paul Feyerabend, Carl Hempel, John Mackie, Karl Popper, Graham Priest, Willard Quine, Mark Sainsbury, Israel Scheffler, Stephen Toulmin, Ludwig Wittgenstein and Lewis Wolpert. Their texts have illuminated my pathways in similar ways to Ariadne's cord of jewels lighting Theseus' way in the bowels of the Cretan Labyrinth.

The fact that the oldest known logical paradox, the Cretan Liar Paradox has its origin on Crete is one of those regular coincidences that force a wry smile from even the most logically tethered, rational minds. The liar paradox simply states: There is a man from Crete, a character by the name of Epimenides, who says that everyone from Crete is a liar. The 'sting in the tail' is he telling the truth or is he lying? If he lies then he must be telling the truth and if he tells the truth then he must lie and so the paradox is born.

The Paradox Hypothesis

The hypothesis I test within this thesis, in conversations with students, colleagues, chosen significant authors and additionally, that incessant internal dialogue, is that studying paradoxes has positive benefits for both students and teachers of science. This thesis explores the value of the study of paradoxes for both science students and science teachers—who are after all students of science as well. The conversations within this thesis reinforce my position that effective communication is only possible if, firstly, teachers and students speak a common language and secondly, the language used is guided by the principles of logic. The conclusion reaches towards confirming that the study of paradoxes offers an arena in which it is possible for students and teachers of science to connect logic, evidence, and truth with science. Where common sense collides with scientific conceptions and conflict arises it is usual, if newspaper articles reflect the common (average) person's view, that these conflicts describe paradoxes. Later examples of common sense paradoxes, such as the French Paradox (Clark, 2002) develop the concept of paradox as perceived by the average person. Although it is far from reasonable to claim that, everywhere that conflicts arise conflicts should be described as paradoxes, I have accepted, after much reading of public media sources and many conversations, that anomaly as paradox is regularly the view that the average person declares. An example of a scientific paradox, such as the presence of Hawaii in the middle of the Pacific tectonic plate is an illustrative contrast. Volcanic activity at some distance from a plate boundary was at odds with the embryonic tectonic theory. This observation became the stimulus for the theoretical 'hot spot' volcanism.

It is essential that students and teachers of science become aware of the ways in which science can proceed. I accept the view promulgated by Sir Karl Popper that science proceeds by conjecture and refutation and therefore logical analysis is paramount. Given my own experience as a research scientist I see Popper's view has sufficient verisimilitude to deny questioning within the scope of this thesis. My assumption that science proceeds by conjecture and refutation seems warranted in the light of my own scientific research. An example of my own research appears in a later chapter.

The Role of Formal Logic

My thesis demonstrates that the process of falsifying conjectures, or indeed failing to falsify conjectures, as a means to change conceptual understandings can only be understood if students have a competent grasp of formal logic. Explicit teaching of formal logic appears to enhance students' ability to assess evidence and utilise this assessment to eliminate alternative, often insufficiently warranted and naïve, scientific conceptions, and replace them with sophisticated conceptions that can be justified with reference to the available evidence.

Additionally, I demonstrate that there exists a need to ensure that the language of science is not an impediment to learning; teachers must ensure that they are aware of the science student's naïve, or immature understanding and inexperienced use of scientific language and how this naïve language impacts on the student's concept attainment. I argue that it is often the case that the students' conceptions are closer to the sophisticated or mature and experienced, scientific notions possessed by the teacher. If a teacher has a poor grasp of the intent and depth of student explanations it is possible that false interpretation by a teacher may result in the teacher falsely lowering the assessment of student achievements. Analysis of the language used by teachers and students exposes potential areas of uncertainty and students may benefit from teachers examining critically the intention of their student's language rather than relying on accepted sophisticated teacher conceptions to determine the veracity of student claims to know. In an example used later (chapter 8), students appear sometimes confused by the concept of density when they say lead is heavier than aluminium when what the actually mean is lead is denser than aluminium. These same students given two equivalent volumes of lead and aluminium can identify the lead as having the greater mass without picking the blocks up. Students understand the concept of density yet the language they possess to explain their understanding is naïve.

Formal logic training seems capable of preventing misunderstandings between teacher and student because when a student and teacher share a common language of logic, the possibility of confusion ought to be reduced in much the same way as interlocutors ought to be speakers in the same language if they are to communicate effectively.

Emerging Questions

Emerging questions within my thesis include such questions as can the traditional Greek concepts of *episteme* and *doxa* assist in the illumination of knowledge claim verisimilitude? I contrast *doxa*, the common or average person's opinion with *episteme* or true knowledge. The epistemological perspective of the claimant influences true knowledge. Seemingly plausible conclusions may contain flawed logic or false premises concealed from plain view. Is it possible the traditional Greek concepts of *episteme* and *doxa* assist in the illumination of knowledge claim verisimilitude? What lies between common opinion and true knowledge is *para-doxa*.

Often, during my research, *aporia* or puzzlement emerges where previously I may have felt that I was on solid ground, *aporia* such as, what is meant by 'valid' as it pertains to evidence? What do we mean when we say that a statement of belief is 'true'? Can evidence that is in disagreement with theory be considered paradoxical? Are these questions of aporetic impasse?

What determines the truthfulness or verisimilitude of knowledge claims? Is a statement of belief *true* simply because the statement is in agreement or correspondence with the facts? What then determines agreement?

What is the role of epistemic curiosity and 'crises in thought', so-called cognitive conflict, and how can my students be assisted to resolve their conflicted truth claims?

Which of my current teaching practises encourage the development of formal logic and is this teaching explicit? Can I teach my students to 'debug' an explanation where a contradiction exists? Can understanding the argument forms *reductio ad absurdum* and *modus ponendo ponens* aid students in examining their epistemological claims? What ‘pedagogical tools’ do I require to assist my students to examine their epistemological beliefs?

Is science unnatural? Can paradoxes exist in nature? What is the role of intuition and common sense in the science classroom? Can I claim that students, engaged actively in knowledge acquisition, generate paradoxes that can be an impediment to understanding if left unresolved? Are, as William Sandoval claims, students’ epistemological beliefs hopelessly naïve or are researchers and teachers views of true student epistemologies deficient in some way?

Can my students benefit from exposure to questioning in the *maieutic* tradition of Socrates?

The Synthesis of an Idea

I constructed a labyrinth of interconnecting pathways based on Douglas Adams’ *Dirk Gently’s Holistic Detective Agency* (1988) , which led much later to my engagement in the doctoral program. My journey probably began in January 1995, when I commenced a Master of Education degree with the University of Tasmania.

As part of the M.Ed. program I was asked to keep a reflective journal and that journal and subsequent journals, I have kept since, if viewed correctly, not necessarily chronologically, form the boundary of the greater labyrinth.

Master of Education Lecturer, Jim Gaite, a psychologist from the University of South Australia, commented on the qualities of a good teacher. He said, “Good teachers are able to show students connections they can’t find themselves.” The finding of these labyrinthine connections is the motivation for my research.

Gaite asked me to read in Alfred North Whitehead, “A fact…is no longer a burden on the memory” (Whitehead, 1929). The constant reference by Whitehead to Russell’s writing led me to seek out and read Russell’s works including, *The Problems of Philosophy* which I found both puzzling and stimulating. I read Karl Popper's writing at this time for the reason of exposing the trilogies; perception-cognition-conception and statement-concept-proposition. Popper's book, *The Logic of Scientific Discovery* (1959), was my first foray into formal logic, abstract formal logic, and epistemology.

Another comment that Gaite made in the course of our dialogue seemed to fly in the face of what my fellow teacher colleagues thought a teacher's role was. He said, "It is not important to teach all the content, merely to stimulate the desire of the student to find out for themselves." Gaite asked me, "What are your methods for stimulating your students?" He asked me to consider the goals of my teaching strategy. Was I able to give an immediate response? I answered, "No", but maybe with time I could. Perhaps a teacher's responsibility is to provide structure to the knowledge and structure is meaningful because the teacher helps to provide the connections, showing the differences and similarities between *doxa*, *paradoxa*, and *episteme*.

When a professor was highly critical of the power of inductive reasoning I felt myself becoming defensive because of my view that inductive reasoning was strongly linked to science. The professor used David Ausubel's Advanced Organiser Model and Jerome Bruner's Concept Attainment Model to contrast inductive and deductive reasoning. Bruner's model, based on inductive reasoning, starts with the particular and leads to generalised statements. Ausubel's model, based on deductive reasoning, leads to particulars through the use of examples.

I found that Bruner's 'inductive' model was given preference in the United States when Bruner was hired by the U.S. President to 'revitalize and invigorate' American curricula, demonstrating the dominance of inductive reasoning in the broader community. Bruner's (1973), *Essays for the Left Hand* became broadly read as a consequence of his appointment. *Essays for the Left Hand* was one of many books I felt compelled to read. Because of the lack of clarity of my intentions the result was the spawning of my labyrinth.

Additional to the books of Bruner, Popper, Whitehead, and Russell, I was introduced for the first time to Jean Piaget and Lev Vygotsky. Piaget and Vygotsky's views on developmental psychology, 'learning by doing' and 'social learning by observation and modeling of the teacher's way of thinking' acted to stimulate me to read many more authors interested in developmental psychology. My mode of entry into secondary science teaching, through my position as a university lecturer, had failed to expose me to developmental psychology up until that point in time. This unusual entry shielded me from the 'normal' enculturation process high school teachers undergo.

I heard my professor say to me that education had changed, "…to value and develop reasoning above all other purposes". Reasoning and the development of reasoning caught my attention because they were apparently absent from my science curriculum. Would it be possible to use Vygotsky's approach and model formal reasoning, including inductive reasoning? I rejected Piaget's approach because of his reluctance to accept that very young children could reason, even in a naïve informal way.

The paradox in Mary Budd Rowe's article *Wait-Time* (2003) was then drawn to my attention. According to Rowe, students recognised with good abilities are often given more wait-time than less able students who clearly need the wait-time more. I needed more time to develop my own understandings perhaps. Over the next few years the possibility existed that modeling formal logic might impact positively on the learning outcomes for my students.

My Teaching Environment

I direct my research questions toward students between 14 and 16 years of age; students in grade 9 and 10 in secondary school. Wherever necessary to conceal the identity of my subjects I use pseudonyms. Where personal communications have been included the author's approval has been granted in writing.

Within this thesis, the body text (Times New Roman) is differentiated from unedited email exchanges (Arial) and journal entries (Lucida). The email exchanges and journal entries are entirely unedited, minor corrections are enclosed by square brackets.

The value of narrative was brought home to me by Tom Barone and was chosen as the means to question the value of paradox study and to show the sometimes circuitous route to understanding. The labyrinthine paths have a target—Greater student understanding of evidence in science through the study of paradoxes.

In the beginning, I confronted many of my assumptions I previously failed to recognise. How influential were these assumptions on my capacity as a science teacher?

I found it very easy to *assume*, however, as a science teacher I must model how to *question*.

Chapter two shows how I have used the Ravens Paradox of Carl Hempel, an explanation of the basic structure of paradoxes and their resolution and indicates an initial examination of my own strongly positivistic background.

Eventually, I was convinced that Science was not in possession of the truth, rather my science expressed truthfulness.

Chapter 2 – Stark Raven Mad

> "I believe he is trying to tell us something," said Balin; "but I cannot follow the speech of such birds, it is very quick and difficult. Can you make it out, Baggins?"
>
> "Not very well," said Bilbo
>
> (as a matter of fact, he could make nothing of it at all); "but the old fellow seems very excited."
>
> "I only wish he was a raven!" said Balin.
>
> "I thought you did not like them! You seemed very shy of them, when we came this way before."
>
> "Those were crows! And nasty suspicious-looking creatures at that, and rude as well. You must have heard the ugly names they were calling after us. But the ravens are different... (Tolkien, 1937)

It is quite usual, living as I do at altitude above the city of Launceston, to see ravens fly past my windows daily. Those ravens cry forlornly, and mockingly, as they wheel past my windows reminding me of my examination of Carl Hempel's Raven Paradox, which is also known as The Paradox of the Ravens (Cf. Hempel, 1937, 1943, 1945; Hosiasson-Lindenbaum, 1940; Kaplan, 1967b; Rescher, 1961; Scheffler, 1963; Scheffler & Goodman, 1972; Tuske, 1998).

The Tasmanian Forest Raven, *Corvus tasmanicus*, is a large bird, called 'crow' by locals due to its large size. Crow is the typical epithet of the larger *Corvus* species. In Tasmania, the population of ravens seems to be quite large, perhaps a product of Tasmania's obscene level of 'road kill'. Marsupial carcasses litter all major and minor roadways, to supply the culinary needs of the scavenging ravens.

The Paradox of the Ravens

Professor Mark Colyvan introduced me to the Paradox of the Ravens first, during an extended series of email communications. Colyvan, from the University of Tasmania's Philosophy Department, indicated to me that

Hempel's paradox, being a paradox of confirmation, should be of interest to me.

I indicated to Mark that I was interested in paradoxes because they,

> …appear to generate from an assumption that is deemed, classically, to be false. That is if one takes the assumption to be false, the paradox exists. If the assumption is considered true a solution is found.

Mark (Colyvan, 2001) replied,

> This is rather an odd way to describe a paradox.

Upon reflection, I would agree. The point I was trying to make, but seemingly had it backwards, was that, in the case of the Paradox of the Ravens the person who hears the Paradox of the Raven for the first time must *first* accept that finding a non-black, non-raven, that is, anything that is not black and is not a raven, *is evidence* for the generalised statement that, 'All ravens are black'. This reasoning reflects the Principle of Confirmation, each and any instance of a generalisation is evidence in support of a generalisation. If this person also accepts the statement is equivalent to 'Everything non-black is a non-raven', based upon the Principle of Logical Equivalence, this leads to the paradoxical conclusion that even a white cup or a yellow lamp confirms the hypothesis, 'All ravens are black'. This thinking illustrates The Principal of Logical Equivalence because each statement has the same logical intent though each might at first appear different from the other.

Mark indicated to me, probably to help clarify my thoughts on the matter, a definition for paradox that is widely accepted. Mark (Colyvan, 2001) wrote,

> A paradox is an (apparently) unacceptable conclusion derived via (apparently) acceptable reasoning from (apparently) acceptable premises (Colyvan, 2001).

This definition is that suggested by Colyvan's namesake, Mark Sainsbury, in his book *Paradoxes* (1995), with Mark Colyvan's addition of the word 'apparently' in parentheses. I took it had the same logical intent to mean that Mark suggested that what is 'apparent' may not be true. Our correspondence on this matter may have been frustrating for Mark because, in spite of his numerous attempts I could not, at that time, grasp the paradoxical nature of Hempel's Ravens. This was to occur much, much later.

In my struggle to comprehend Hempel's Ravens I had taken great notice of the use of 'All', what is referred to as the universal quantifier, as opposed to the existential qualifier, in formal logic, in Hempel's hypothesis. I thought that The Paradox of the Ravens could lead, to logical yet evidently false conclusions such as 'All ravens are white' and therefore the logic must be unsound if the conclusions could be shown to be contradictory.

The paradox exists because of an assumption that is fallacious.

I asked myself, how is the Paradox of the Ravens illogical? It must contain flawed reasoning or false assumptions. I aligned The Paradox of the Ravens with inductive reasoning and therefore felt uneasy about the potential collapse of my scientific edifice.

I used the expansion of metal in response to heat as a model on which to base an interrogation of the logic involved.

Inductive reasoning allows us to say,

Metal x expands when heated

Metal y expands when heated

Metal z expands when heated

Therefore all metals expand when heated - acceptable logic in science

I noted that the generalised statement, 'All metals expand when heated' was logically acceptable and useful, but *failed* to note if, 'All metals expand when heated' was necessarily true.

The absurdity that a white cup confirms the hypothesis that, 'All ravens are black', suggested by The Paradox of the Ravens is logically similar to the notion that non-metals non-expanding when heated are evidence in support of the hypothesis, ‘All metals expand when heated’. ‘All matter expands when heated’ is something evidently untrue, exemplified by the expansion of freezing water as temperature decreases. Water expands as it cools due to strict alignment of water molecules into a crystalline lattice and is evidenced by three recently recognised (Esposito, De Risi, & Somma, 2007) transition temperatures, referred to later. The property, or predicate, *expansion* of the metal was the same as the *blackness* of the ravens, and therefore, if the logic exemplified by The Paradox of the Ravens was acceptable, then it was equivalent to claim, ‘Non-expanding non-metals’ would constitute reasonable evidence for the hypothesis that, ‘All metals expand when heated’.

Argument Forms

I was using forms of argument used regularly in science; *reductio ad absurdum*—logically arguing to a contradiction thereby denying the premise upon which a conclusion is based, *modus tollendo tollens*—If A then B, not B therefore not A and *modus ponendo ponens*—If A then B, A therefore B. Deducing contradictions from a set of premises had allowed me to reject one or other premise as false, and I must confess that I was motivated to reject all paradoxes as sophistic because of these argument forms. *Reductio ad absurdum* and *modus ponens*–the usual way this form of argument is expressed–show that, reduced to absurdity, the conclusions would indicate false premises because, the argument being sound, there would be no way the premises *could* be true and the conclusion contradictory. An alternative, as happens regularly in science, is to accept as *true*, what *appears* contradictory. The expansion of metals provides a comprehensible argument that non-expansion of non-metals being evidence, that is evidence that does not adhere to a particular case, in support of the generalisation that ‘All metals expand when heated’, is absurd, and therefore, confirms my proposition that all *such* ‘white cup’ evidence is absurd, that is evidence that does not appeal to the particular case is absurd.

Resolving Paradoxes

Today some paradoxes are resolved although previously recognised as fallacious (deliberately and playfully manipulated). One example of resolving a paradox is the Barber Paradox that can be resolved by doing some logic, rejecting the existence of the barber who 'Shaves all those who do not shave themselves' because we cannot adequately answer the question, who shaves the barber?

Olbers' Paradox of, 'A night sky lit as bright as day as though the sky were filled with numberless gleaming stars' has been resolved, by doing some science, with scientists actually looking into space. (Poundstone, 1990, pp. 152-157)

I thought logicians were playing favourites with the so-called cataclysmic paradoxes which they chose judiciously to leave unresolved and elevated to full status, resolving instead shallow or weak paradoxes. Scientists seemed then, and still are today, to be less capable of leaving contradictions unresolved, developing new experiments and altering their hypotheses in response to further observations. According to expert logicians such as Sainsbury (1995), Quine (1966), and Colyvan (2001), the sophisms or deliberately fallacious paradoxes, like the Barber Paradox, were elusive and could be viewed, by untrained people, as genuine. Algebraic fallacies of the kind where 1 is shown to equal 2 (Cf. Bunch, 1997) start with an *obvious* flaw, that would appear *only* to people familiar with the mathematical principles, which are held in abeyance by the untrained.

Perhaps, logical paradoxes existed because of the nature of logic. My emerging question then became,

> *What is the purpose of the paradox in philosophy?*

Thought Experiments

Olbers' Paradox, an exposition of which can be found in Thomas Kuhn's *The Structure of Scientific Revolution* (T. S. Kuhn, 1962), offered me a promising way to inquire into links between science, philosophy and paradox. Olbers' Paradox occupied a significant amount of my thinking space because it demonstrated the role of paradox and anomaly in the study of science. Olbers' thought experiment showed how thought alone could provide a way forward when experimentation was out of the question due to the limits of technology. (Barrow, 1999; T. S. Kuhn, 1962; Quine, 1966; Silver, 1998)

The ancient Greeks, Heraclitus and others, founded the tradition of thought experiments. Aristotle was expounding them, as a means to provoke thought. Natural philosophers or scientists carry this tradition forward to the present day. (Barrow, 1999; Cohen, 2005; Quine, 1966)

Galileo was able to resolve his puzzlement concerning which of two dissimilar weighted cannon balls, objects of different density but equal size, would hit the ground first, not by dropping them from the leaning tower of Pisa, but by performing a thought experiment. Martin Cohen examines Galileo's thought experiment and others in *Wittgenstein's Beetle and other Classic Thought Experiments* (2005, pp. 33-36). IF it is known *a priori* that, 'A moving object, such as a horse and cart, would slow if weight were added to it' and he assumed Aristotle's claim that, 'Heavy objects fall faster than light objects' THEN it would necessarily be true that two dissimilarly weighted cannon balls, joined by a rigid rod, when dropped from the same height simultaneously would initially travel side by side with the cannon ball of greater mass accelerating at a greater rate until the cannon ball of lesser mass trails behind the heavier cannon ball and thus, because of the rigid rod that ties them, effectively increasing the mass of the heavier cannon ball which must then simultaneously increase acceleration. Galileo assumed Aristotle's premise and because we know *a priori* that added mass will slow our moving object this led to the paradoxical conclusion that the acceleration would both increase and decrease. Having discovered a contradiction Galileo rejects Aristotle's premise because by reference to thought alone he knows that adding mass will slow our moving object. It is therefore possible to conclude that objects of different mass do not fall at different rates. This thought experiment referred to by

Cohen as Galileo's Gravitational Balls is an example of the argument form *reduction ad absurdum* (Cohen, 2005, pp. 33-36).

Having illustrated something of the tradition of thought experiments, I now return to Olbers. Olbers assumed or hypothesised that the universe was infinitely large with an infinite number of evenly spaced stars, and that, if this were so, the night sky would be, 'lit bright as day' because, in every direction one looked a star would be at the end of the line of sight. Because the night sky was not lit as bright as day, Olbers viewed this contradiction of his plausible premise of a universe populated with an infinite number of evenly spaced stars as paradoxical.

The night sky is not lit bright as day, and therefore, the proposition that the universe is infinite and populated with an infinite number of stars must be false or some other explanation must be developed to explain away the apparent contradiction. This simple explanation for rejecting an infinite universe is plausible. Yet alternatives exist to resolve Olbers' Paradox, including, equally acceptably, that not all the light from this infinite number of stars has reached Earth. Some of my conversation, with Colyvan, focussed on Olbers' Paradox. I had rejected Olbers' hypothesis of an infinite universe, populated by an infinite number of evenly spaced stars, by *reductio ad absurdum* argument, as a normal process of science. The scientific argument compels or forces the scientist to modify the hypothesis as a consequence of new information coming to light.

If a premise is accepted, and yet leads to a conclusion that is apparently false, revising the premise to accommodate the observations that contradict the premise solves the difficulty.

Solving Hempel's Ravens

Because of the ease with which I resolved Olbers' Paradox, I was then encouraged to tackle the more difficult, still scientifically relevant case, of Hempel's Ravens. I wrote Mark.

> Hempel's Ravens implores you to accept that non black non ravens are evidence that all ravens are black. How can this assumption be apparently acceptable when it clearly leads to absurdity, non black, non white, non green, non blue…non ravens being evidence that all ravens are black, white, green, blue etc.
>
> I say the premise non black non ravens being evidence that all ravens are black must be erroneous and therefore doesn't fit your definition.

Mark's definition for paradox emphasised 'apparent'. I 'homed in' on the term as a means to reject all paradoxes because their conclusions were unacceptable. I neglected to consider that many paradoxes, and in particular Hempel's Ravens are based upon the conclusion *via* sound reasoning, upon two universally acceptable principles; one, if one of a pair of logically equivalent statements is true, the second statement must also be true, and the other, that any instance of a generalisation is evidence in support of the generalisation. I understand now, as I write, the strength with which I could hold these two principles had to be far stronger than at the time when I rejected weakly Hempel's premise that non-black non-ravens are evidence that all ravens are black, on the basis of an apparently unacceptable conclusion.

My new view of Hempel's Ravens led me to explore the paradoxes that shake the concept of truth in relation to evidences and generalisations that derive from them. The modest understanding of Hempel's Ravens that I had previously held was changed. I was fully aware of the tentative nature of science. My claims to know anything had limitations, limited by the rejection or acceptance of assumptions upon which any claim is based. Nevertheless, I was ever hopeful that my students would learn about science's truthfulness, and not science *as* truth.

I was disparaging my students constantly for claiming that they proved anything in regard to experiments they conducted, suggesting that they simply provide a *measure* of supportive evidence. While that was valid I would also have emphasised that statements could be falsified *with certainty,* on the basis of one single piece of refuting evidence. Then Thomas Kuhn's (1996) book, *The Structure of Scientific Revolutions* and Olbers' Paradox helped me reject this ‘certainty’ notion, that statements could be falsified by a single piece of evidence, as naïve.

I really wanted to know why Mark used the word ‘apparently’ in his definition of paradox. I wrote that I viewed knowledge claims as polarised. However, they could be, true or false, graded between truth and falsehood, both true and false (if Priest’s dialetheism is accepted (Priest, 1998), or neither true nor false. This view revealed an attitude spawned out of the empiricism of my undergraduate training. I was taught, what evidence we had *was* truth.

My Early Arguments in Science

Four years after my undergraduate training the views of my knowledge claims had not changed. I wrote an article, published in Modern Medicine of Australia (Lockwood, 1990) entitled, *The Diving Reflex*. It concerned a primitive reflex response brought on by immersion of the face in cold water. Animals, like whales and Weddell seals, benefit from the diving reflex. Many animals are able to sustain long periods of submersion without risking anoxia which could lead to their death when anoxia deprives oxygen to vital organs, especially the brain. Similarly, humans exhibit bradycardia or slow heart rate, and vasoconstriction of blood vessels, mediated by immersion of the face in water, as a vestigial reflex, perhaps indicative of our aquatic past.

For me, my article was a refutation of a claim by David Ross, another scientist and medical practitioner. Ross (1990), suggested that the diving reflex could be used to terminate chronic attacks of paroxysmal supraventricular tachycardia (P.S.T.), a condition whereby the heart rate remains elevated for extended periods of time, and causes great anxiety in the afflicted patient. In his article, Ross advocated using ice-water as the stimulus for the diving reflex. My refutation included a modification of Ross’s claim. Although Ross’s technique would indeed stimulate a diving reflex, I believed the use of ice-water was unnecessary, and potentially life-threatening, due to the likelihood of adrenalin discharge. I believed extreme cold caused adrenalin release in, leading to potentially fatal ventricular dysrhythmias.

What I subsequently recognised from Ross's response to my article was that the use of the diving reflex in clinical practice, had also acknowledged the risks associated with using very cold, water and were, nevertheless, paradoxically, advocating the use of ice-water in the treatment of P.S.T. In my article critical, of Ross's technique I wrote, "There is an apparent contradiction, in that the temperature of water used (2-5^{o}C) to elicit the diving reflex by many groups is considered by these same groups to be potentially harmful to their subjects with supraventricular paroxysmal tachycardia (Lockwood, 1990, p. 13)."

The apparent contradiction triggered my reply to Ross's first article. Using ice-water to treat one malady could trigger another that could be fatal. I had viewed Ross's claim as false because, in my own mind, it was illogical to advocate the use of ice cold water *and* warn against the potential risks of using ice-water, especially, when I knew higher temperature water was capable of stimulating the diving reflex. I saw the problem as 'black and white'. After Ross's second article I accepted that Ross was advocating a perfectly reasonable action. Failure to treat P.S.T. may have led non-hospitalised patients to die prior to receiving more advanced drug-based forms of life support. In my second response to Ross, I suggested truthfully—by truthfully, I meant in a seriously thoughtful way—that higher temperatures were safer, and the 'literature' supported this claim. However, Ross's suggested use of ice-water *had* implied lower temperatures when he may have been advocating the use of a mixture of ice and water at a temperature significantly higher than 0^{o} Celsius. In my first reading of Ross's article and from my own declarative knowledge, I had inferred that ice-water meant 0^{o} Celsius.

Ross's response (1990) to my first challenge, denied the suggestion of increased adrenalin related cardiac oxygen consumption and increased arterial blood pressure on the basis that patients presenting with P.S.T., "[patients]…already have high levels of sympathetic tone, [adrenalin], with little room for further increase" (p. 13). In addition, Ross presented data from 100 patients who showed no negative consequences from the use of a mixture of ice and water. Ross's response convinced me that I had drawn a false conclusion on the basis of a false premise. At first, it appeared wrong to administer ice-water. Reflecting on truthfulness, rather than truth, in science, I was able to see that Ross's actions were scientifically justifiable.

Both Olbers' and Hempel's Paradoxes had shown me that the truthfulness of a scientific claim can be challenged without the need to reject the claim altogether. I found that, under most conditions, minor modifications of claims can ameliorate concerns over the validity of the claim. In the logical exposition of the claims of Ross and Olbers, the modification of their claims ameliorates concerns. In the case of the Paradox of the Ravens, I had found Hempel's dependence on the two Principles, Logical Equivalence and Confirmation rigid.

Mark had suggested looking at Russell's Set Paradox, as an illustration of a cataclysmic paradox and Russell's Barber Paradox, as an example of a weak paradox. Mark's view was that Russell's Barber Paradox was not a paradox at all. Examining both paradoxes proved to be useful because I eventually recognised the breadth of paradox types and the need for students to link the study of paradoxes to the study of formal logic, if they were going to be able to draw evidenced or warranted conclusions.

Hempel's Ravens Place in the Science Classroom

Driver (Driver, Newton, & Osborne, 2000, p. 287) said of her own study,

> This study presents the rationale for a research program in the area of argument in science- an area to which science education has only given scant attention. As argument is a central feature of the resolution of scientific controversies, it is somewhat surprising that the science teaching has paid so little attention to a practice that lies at the heart of science.

When I told Mark that I believed, 'Non black non raven' was a premise, he riposted that it was a conclusion, showing me that I had not fully understood the various analyses of Hempel's Ravens. Mark supported the view that most paradoxes are not sophistic in nature, and suggested that to research Russell's paradoxes would help me make sense of the structure of the logic involved. The circular nature of the reasoning pertaining to Hempel's Ravens confused me. I thought "All non-black non-ravens" was a premise, and not a conclusion. What I claimed was, 'The Logical Equivalence Principle is inapplicable in the case of Hempel's Ravens' and that 'All non-black non-ravens', constituting supportive evidence for all ravens being black, ought not to be accepted on the basis of equivalence with, 'All ravens are black'. Mark was willing to hold in abeyance his disbelief as he held on to the Principles of Logical Equivalence and Confirmation. I did accept the Logical Equivalence Principle but I was not yet ready to suspend my disbelief.

I was not schooled in logic. Perhaps I missed what Mark *was* trying to tell me. Until I could discover an answer to the question, what are the premises that allow me to conclude that non-black non-ravens are evidence for 'All ravens are black', the advancement of my conceptual understanding of paradoxes was stymied. By 'premise', I meant that the term premise represented an idea put forward for consideration from which the inferences or conclusions were drawn. I saw the premise, in the case of Hempel's Ravens, as the statement, 'All ravens are black'. Mark was adamant this statement was the 'conclusion' for which we were trying to find supportive evidence. Contradicting Mark, I construed that the statement, the hypothesis, 'All ravens are black' as the assumption, the premise, used for the basis of reasoning and therefore, assumed 'All ravens are black' to be true for the purpose of making inferences about the validity or otherwise of 'All non-black non-ravens' being evidence in support of the hypothesis.

Sainsbury says there are three ways of rejecting a paradox: the assumption is deniable, the reasoning is invalid or the conclusion really is acceptable (Sainsbury, 1995, p. 1). I saw a deniable assumption imbedded in 'All ravens are black'. Mark had viewed 'All ravens are black' as the logically inferred conclusion on the basis of the acceptance of the principles already mentioned.

Following Quine (1966), Scheffler (1970), Scheffler and Goodman (1972), Kaplan (1967a, 1967b), Tuske (1998), Mackie (1963, 1973) and Ayer (1952), I could state Hempel's Ravens differently. Assuming 'All ravens are black', and accepting the Principle of Confirmation (any instance of a generalisation is supportive of the generalisation) and accepting that the Equivalence Principle is considered '*a priori*' knowledge, non-black non-ravens are evidence (the absurd bit) in support of the conclusion that all ravens are black. I refuted the paradoxical conclusion on the basis of one observation—I saw an albino raven at my local petting zoo.

I asked Mark to clarify what he meant by highlighting the word 'apparently'. I thought he had implicated the notion of perception existing only in the mind. Mark's email shouted his response:

> Absolutely not! I simply mean that what may seem like a true premise, valid reasoning or unacceptable conclusion may, in fact, be false, invalid or acceptable, respectively.

My belief that any premise, being a statement, *must* be either true or false, was also rejected. Authoritatively, Mark pointed out that his term, "apparently plausible" did not imply "necessary truth (or even truth)". Mark was suggesting that:

> …the truth of the premise was determined on a case by case basis depending on the subject matter and might involve doing some physics, some mathematics or some semantics etc.
>
> Most paradoxes can be resolved one way or another, but the costs are usually high (e.g. giving up unrestricted comprehension because of Russell's paradox) and they usually reveal deep insights about the area of study in which they arise. Russell's paradox is no mere sophistry --- it brought about the rethinking and reworking of all of set theory I think you would do well to reflect on the difference between Russell's paradox (which I take to be a genuine and serious paradox) and the so-called Barber's paradox (which is not a paradox at all)

Russell's Set Paradox, the Barber Paradox and the Liar Paradox were to develop my idea that, 'Paradoxes are indicative of the need for shift in scientific understanding', perhaps even a Kuhnian 'paradigm shift'. In spite of not continuing the dialogue with Mark, the ravens wheeling overhead constantly reminded me of my debt of gratitude owed to Carl Hempel and, more importantly, to Professor Mark Colyvan for his persistence. Years later, my attention can readily gravitate toward Hempel's Ravens, although few people I know grasp its significance in the development of scientific knowledge or common sense.

I eventually wrote an exposition of Hempel's Ravens for Jon, who was examining knowledge claims regarding work in chemistry, in particular, patterns in chemistry and their associated generalised statements.

Claim 1 – 'All ravens are black'

Observation 1 – an ornithologist sees a black raven

Conclusion 1 – claim 1, 'All ravens are black', is supported by this observation

Claim 2 – 'No raven is not black' is logically equivalent to the claim that 'All ravens are black'

Claim 3 – 'All non-black objects are non-ravens' has the same linguistic meaning as claim 2

Observation 2 – see a non-black non-raven [see a white cup or a yellow lamp]

Conclusion 2 – claim 3 is supported by an observation of a non-black non-raven

Conclusion 3 – claim 2 is supported by observation 2

Conclusion 4 – claim 1 'All ravens are black' is supported by observation 2 observing a non-black non-raven, because of the equivalence principle (Claims 1, 2 & 3 are logically equivalent)

Could I help Jon understand, Conclusion 4, the observation of any object that is not black and not a raven supports the generalisation, 'All ravens are black'?

To many people this would seem absurd? However, would he be able to see that Conclusion 4's validity only rests upon the two principles—The Principle of Confirmation that any instance of a generalisation is evidence in support of the generalisation, and The Principle of Logical Equivalence, both of which are both known '*a priori*', by appeal to reflective thought.

Jon used the Principle of Confirmation to provide supportive evidence for the claim that 'All carbonates react with acid to produce a salt, carbon dioxide and water'. His conclusion came after the addition of acid to a total of eight known carbonates with each carbonate yielding carbon dioxide, a salt and water. Combining vinegar and bicarbonate of soda may be a familiar effervescing example of this type of reaction. After witnessing gas being given off, and testing for the other products of eight different acid-carbonate reactions Jon readily accepted that the reactions, he witnessed were evidence that, 'All carbonates react with acid to produce a salt, carbon dioxide and water'. Jon believed he had proven his generalisation.

Jon accepted the first principle described above and therefore accepted, in the case of Hempel's Ravens, the logic that Observation 1 confirmed Claim 1, he also accepted that Observation 2 was evidence in support of Claim 1 because he could make sense of the logical equivalence of statements 1, 2 and 3, when they were held together, though he did not accept that, 'All ravens are black' was true.

Then, as if in a flash, Jon separated logic from truth. What is logical is not necessarily true, he realised it is possible to have a logical syllogism, a series of statements that logically leads to a conclusion built from, for example, false premises. In such a case, in spite of the logical argument the conclusion is false because at least part of a premise, or one or more of the statements is false.

In later experiments performed by Jon, he disconfirmed or refuted the claim that 'All carbonates are insoluble' when he discovered three soluble carbonates. Jon was able to recognise that although his original conclusion, 'All carbonates are insoluble' was valid, it was not true, and this was born out by further experimental observations. Whilst before, he was not hesitant in believing that; All carbonates react with acid to produce a salt, carbon dioxide gas and water he had no observation that refuted his claim. In later experiments he recognised the need to develop critical scepticism of the justification of claims regarding his first experiments, that is, he was more reluctant to be a strong advocate for his original conclusion.

I believed that patterns and pattern anomalies were stimulating for students. I believed that distortion of patterns was a useful instrument for focussed teaching. I thought that misconceptions within science arose because students couldn't separate valid evidence and invalid evidence. Students like Jon might not have done this earlier because they failed to recognise that knowledge generates through the logic of scientific discovery. Students lacked the knowledge of how experienced scientists used evidence to support conclusions. Students like Jon needed a theory of knowledge in order to explore inductive reasoning, and I, as an experienced scientist, ought to have been able to provide experiences in analysing evidence to support their developing scientific knowledge.

I had struggled with The Paradox of the Ravens for some time. I was both astonished and annoyed that Jon was able to grasp the essence of this paradox so quickly. I had presumed that my scientific training, within the fields of biochemistry and botany, had caused my difficulties. I had assumed that paradoxes were sophistic in nature and, teachers and students should reject the absurdities that led from the logic. Trapped as I was within my scientific view, I could not do as Jon did, simply accept the logic—separately questioning the truthfulness of the conclusion.

I could now see a means where a study of paradoxes and a practice of logic could help students perceive science's *truthfulness* not science's *truth*.

Chapter 3 – The Story of Erasto Mpemba – a case study

> Two buckets of water; cold water (15^{o}C) and warm water (55^{o}C) are placed in the open air over-night. The temperature fell to minus 5^{o}C. Explain which bucket of water freezes first?

This assignment above was part of my students' work in chemistry and inspired an opportunity for students to demonstrate what they were learning about testing knowledge claims of others. I had every expectation that students would begin by using smaller volumes of water in smaller containers than buckets, and draw conclusions after when they saw what happened, and then they would try the same in larger containers, all to gather evidence to draw their conclusions.

Whilst my students were seeking information about 'water', 'freeze', 'cold', and 'hot' on the World-wide Web, Jon, who had understood the Paradox of the Ravens, discovered a story about the Mpemba Effect and shared it with the other students. He knew it would appeal to me, perhaps because of its resemblance to Hempel's Paradox.

This was the beginning of a fascinating discovery that I made whilst working with my students. The story illustrates possibilities for students to use the forms of argument that are utilised in the study of paradoxes, and, at the same time, demonstrates how students can influence their teacher to reflect on their own thinking. Teachers can be as dogmatic as students when they believe that they hold the *truth* in their hands.

Finding Erasto

When I read Jon's story of the Mpemba Effect in his assignment, and I realised how important it could be to show my students the power of logic in resolving a scientific paradox, I immediately sought a copy of Mpemba's original article in the journal, Physics Education (Mpemba & Osborne, 1969). The story of

Erasto Mpemba—his relationship with his teachers, and his curiosity—captured the students' imagination.

In 1963, the young Erasto was in the 3rd form at Mkwawa High School in Iringa, Tanzania. It was the habit of the boys of the school to make their own ice-cream using the school's refrigerator. In the rush to get his recently boiled mixture of milk and sugar into the refrigerator-freezer, before all the available trays were taken, Erasto neglected the cooling period that was usually required, and was to observe a counter-intuitive, paradoxical result. When compared with a recently boiled, but cooled sample of milk and sugar, placed in the freezer by another boy at the same time, Erasto discovered that his hot sample had frozen, whilst the ice-cream of the other boy remained slurry, and was yet to freeze.

Erasto asked his physics teacher to explain what had happened. His physics teacher responded in this way, "You were confused, that cannot happen" (Mpemba & Osborne, 1969, p. 172). Erasto accepted his teacher's rejection of his notion that non-Newtonian cooling was possible—a teaching opportunity was squandered. After this incident, Erasto was told by a friend, who worked as a cook, that he recommended ice-cream mixture be placed into freezers *whilst still hot* to *speed up* the freezing process.

Erasto studied hard for his 'A' levels creating an opportunity to raise the issue of the counter-intuitive observation with another teacher. The second teacher took an additional step to ignoring Erasto's claims; he openly mocked Erasto's suggestion, that non-Newtonian cooling was a reality.

Young Mpemba, to his credit, was not deterred and constructed a simple experiment to determine, perhaps once and for all, the validity of his paradoxical claim. Taking two 50mL beakers, he filled one with boiling water, and one with tap water. Because of the local African climate, the temperature of the tap water was 35^{o}C. Erasto placed the two beakers in his laboratory freezer compartment and waited expectantly. After one hour, Erasto noted that all the water had not been turned into ice but, that more of the *hot* water had been transformed into ice, when compared with the water that was initially cooler.

When, one day, University Professor, Denis Osborne visited Mkwawa High School, Erasto confronted him with these results. Instead of the usual outright rejection, Erasto's claim received Osborne's full and interested attention. Had Erasto conducted any experiments to test the validity of the claim, Osborne asked? Luckily for Erasto, Osborne, "remembered the need to encourage students to develop questioning and critical attitudes (Mpemba & Osborne, 1969, p. 173)."

Later, when Osborne returned to the University College, which would become the University of Dar es Salaam in 1970, he asked one of his technicians to repeat Mpemba's experiment. Osborne's technician reported, the hot water appeared to freeze before the cold but he would, "keep on repeating the experiment until we get the right result (Mpemba & Osborne, 1969, p. 173)."

The technician's response was similar to the responses of my students, faced with similarly anomalous or incongruent results. The technician and the students deny their observations and resolve to support their already existent views. Their response of denying their observations, is reported by Brewer and Chinn, as one of seven responses to anomalous results. (Cf. Brewer & Chinn, 1994; Chinn & Brewer, 1993)

As Brewer and Chinn (1994) put it, "An individual currently holds theory A. The individual then encounters data that appear to be inconsistent with theory A. The anomalous data may or may not be accompanied by theory B, which is intended to explain much of the domain of data explained by theory A, plus the new anomalous data" (p. 304). In response to anomalous data, Brewer and Chinn claim, individuals would enact one of seven possible responses: ignore data; reject data; exclude data; hold data in abeyance; reinterpret data to retain theory A; reinterpret data making *ad hoc* adjustments to theory A; or reject theory A in preference to theory B. Similarly, Barbara Koslowski (1996) reports that,

> …anomalous evidence that includes an explanatory mechanism has a greater effect on causal than non-causal beliefs, that is, on precisely the sorts of beliefs that Deanna Kuhn (1989) and others found to be the more resistant to change. (Cf. Koslowski, 1996, p. 257; D. Kuhn, 1989, 2005)

At the time my students were completing their assignment there was no known explanation for the Mpemba Effect. Although the acceptance of the conjecture of Katz (2006), that dissolved solutes were the causal agent, partially addressed the anomaly, the anomaly persisted and my students, like Osborne's technician, choose to reject the data, rather than alter their theory regarding the cooling process.

The paradoxical observation – hot water freezing before cold water, is based on the theory of Newtonian cooling explaining heat loss from a body of water. Moving particles of water slow, losing heat, during collisions with other particles in their environment. The other particles would speed up or gain heat in response to collisions with the faster moving water particles. If it is assumed that Newtonian cooling alone controls the rate of temperature change then it is reasonable to conclude that the cold water would freeze first.

Explanations for the Mpemba Effect included: dissolved gases (Wojciechowski, Owczarek, & Bednarz, 2006), supercooling (Auerbach, 1995; Esposito et al., 2007), mote-based nucleation (Knight, 1996), evaporation (Kell, 1969) and dissolved minerals (Katz, 2006). Many papers written about the Mpemba Effect offer little more than conjectures, such as those expressed by Katz who himself presented no empirical experimental evidence.

Paradox Resolution Strategies and the Mpemba Effect

Along with two Grade 9 Science students I embarked first, on an attempt to duplicate the original experiments of Erasto Mpemba, and, then a series of controlled experiments. To repeat Mpemba's experiments, my students and I placed sugared milk and heated sugared milk into a freezer at minus 17^{o}C. We put the milk in standard ice-cube trays to emulate Mpemba's original actions. In this experiment, the heated milk was still slurry, when the cold milk was frozen. Due to the difficulties of dissolving large quantities of sugar in cold milk, the sugar was not fully dissolved in the cold milk prior to placing the ice-cube trays in the freezer compartment. We believed this may have been the case for Mpemba who, as you will gather, had fairly warm water coming out of his cold water tap. Unfortunately, because of the lack of experimental ‘control’ this experiment provided us with no valid conclusions.

After the initial unsuccessful, and really rather disappointing, trial to repeat Mpemba’s original experiment, to witness the counter-intuitive freezing of hot milk prior to cool milk, we conducted more rigorously controlled experiments.

We placed new 50mL, ‘Schott Duran’ Pyrex beakers, together with weighed samples (approx. 40g) of deionised water (Andel Agencies, ‘Aqua-Health’ CT -3 water filter) into a freezer at -17^{o}C. We recorded the temperature of the water samples using a MIR-S2000 thermocouple linked to a JCS33A-R/M Shinko controller (Temtrol Technologies Pty Ltd, Tasmania). The thermocouple was attached to a 3 metre wire, ensuring we could keep the door closed during the experiment to prevent rapid heating of the freezer compartment when opening and closing the freezer compartment door. This heat shock, due to the opening of the freezer door, has been suggested by Esposito (Esposito et al., 2007), as a nucleation source which may preclude the supercooling of water. Esposito and others (2007) and Auerbach (1995) implicate supercooling as the source of both the counter-intuitive, paradoxical effect and a statistical effect that obscures the consistency longed for by my students and I.

Physicist, Charles Knight showed that there was a general tendency to decrease nucleation temperature, the temperature at which ice crystals begin to form, by as much as 10^{o}C, with repeated freezing of the same water samples (1996, p. 524). The fickle nature of the Mpemba Effect is the source of problems for scientists and may explain their lack of willingness to conduct controlled experiments, instead of restricting their actions to commenting on the Mpemba Effect. My students and I were unable to find more than a handful of articles inquiring into the Mpemba Effect where scientists had collected empirical evidence.

The assignment I set for my grade 9 students had inspired our experimental research on the Mpemba Effect. Students initially indicated to me that they believed that the water that had started at 55^{o}C *freezing first* was implausible. However, given that it was me asking them to undertake this assignment, they concluded *wrongly* that their reaction, that it was implausible for hot water to freeze before cold water, was to be prejudiced. Because of my strategy of utilising paradox as a teaching strategy, my students concluded hot water *will* freeze before cold water. In this instance, I misled my students, when they assumed that the assignment was part of my strategy of utilising paradoxes when teaching.

I emailed a colleague, physicist Ian Newman, of the Australian Institute of Physics (A.I.P.). This email shows my frustration, with my class, failing to undertake practical experimental work. Ian had assisted me, through the A.I.P., to secure a grant for purchasing the thermocouple used in our later controlled experiments.

> Dear Dr. Newman
>
> Some students I teach have recently come across some information about the Mpemba effect. Are you aware of this effect?
>
> I proposed a question about two buckets of water (55 and 15 degrees Celsius) the question was simple enough. Which would freeze first if exposed to [an] ambient temperature of minus 5 Celsius?
>
> Most students have chosen to respond by referring to the Mpemba effect and have not conducted any experiment, much to my chagrin.
>
> Can you advise me?
>
> Steve Lockwood

In his reply, Ian told me about his familiarity with the Mpemba Effect and its *folkloric* nature.

Dear Steve

Yes! I doubt that the Mpemba effect has anything to do with your particular question. These days students will surf the Web, rather than getting their hands wet as we enjoyed doing. There is a lot of "stuff" on the Mpemba effect. It is not a well-defined affect and has attracted a superficial folklore. It doesn't always "work". New Scientist had a summary article a few months ago, I forget just when.

My understanding is that, if the water has been boiled it can freeze more quickly in some circumstances than water that has not recently been boiled. It is something to do with the amount of dissolved gasses. I guess that your students were careless in failing to distinguish between "hot" water and "boiled" water! Chide them!

To avoid the Mpemba effect, one should boil two samples, put both in the frig [sic] for a while: leave one there until it is near 55C; the other until it is near 15C only then put the two into the -5C freezer. Otherwise (which I guess was the implication of your question), just warm each bucket up on the stove to achieve the chosen initial temperatures (no boiling). (You may have to modify timing so that the two samples reach their required initial temperatures at the same time.)

Those are my thoughts.

Good to hear from you. We have been pleased about the Minister's "Refining our Curriculum" paper.

Regards, Ian

Marcus Chown authored the New Scientist article to which Ian referred in his email reply. Chown (2006) reported the conjecture of Jonathan Katz, of the University of Washington at St Louis, that the Mpemba Effect was due to dissolved solutes, particularly the solutes, calcium and magnesium carbonate. Chown's article also quotes Richard Muller's effusive comments that, "Katz's analysis of the Mpemba effect is deeper and more rigorous than anything else on the subject (p. 10)."

Muller's conclusion is astounding, given the wealth of evidence, such as the evidence reported by David Auerbach in 1995. Auerbach showed that the

Effect could be seen in double distilled, thereby solute-free, water. Auerbach's article is often reported by researchers interested in the Mpemba Effect and is available on the World-wide Web.

What did inspire my students to dispense with practical experiments in this situation? It is true that my students failed to analyse the question sufficiently, jumping to the conclusion that I had presented a paradoxical phenomenon. When my students failed to conduct practical experiments, an interesting discussion ensued. The students determined that given no commonly accepted scientific explanation existed for the Mpemba Effect; they doubted their capacity to conduct their own experiments.

This response validates Kuhn's and Koslowski's comment that without a theoretical explanation it was less likely that theory change would occur, more likely would be the rejection of the evidence. However, in this case, students rejected the intuitively *plausible* explanation, involving Newtonian cooling, in favour of the counter-intuitive and *implausible* Mpemba Effect. My students' conclusion that the bucket of hot water would freeze before the cold water was unsupported by experimental evidence, and instead relied on the authority of authors such as Monwhea Jeng. Jeng's Web-based article, 'The Mpemba Effect: When Can Hot Water Freeze Faster Than Cold?' (2006) was a common reference used by my students.

Before I presented my class the following year with the same assignment question, I read to them my email exchanges with Newman revealing my shock and astonishment that past students had failed to conduct their own experiments. I explicitly encouraged my students not to fear conducting their own experiments. I wanted them to examine the veracity or *truthfulness* of their claims about the 'buckets of water' by experimentation. Many students were still lured by the Mpemba Effect. Yet, their own experimental observations led many to reject the Mpemba Effect.

One student, Doug, found that, "…this clearly shows that the Mpemba Effect is simply not true." In Doug's experiment he stirred water samples to prevent heat loss only from the water's surface. Doug concluded that the top of the hot water samples had frozen first because the surface of the water was at a lower temperature than the core of the water in his polystyrene cups. Doug noticed that the cold water sample was frozen at exactly the same time if the two water samples were stirred regularly.

Doug's stirring had provided the nucleation required for ice crystal formation and prevented supercooling, thus removing the unpredictable component reported upon by Auerbach (1995). Auerbach claims, "One of the main results of these studies (in particular 23,24,26,29) is that neither the time taken nor the freezing temperature are predictable" (p. 882).

When the Mpemba Effect was analysed by my students using logic developed from their study of paradoxes (Cf. T. S. Kuhn, 1962; Mackie, 1973; Movshovitz-Hadar & Hadass, 1990; Rastovac & Slavsky, 1986; Sainsbury, 1995; Sorenson, 2003; Welch, 1980), they chose to accept the paradoxical conclusion. To resolve paradoxes, according to Sainsbury (1995), our choices are: to reject the logic, to reject that the conclusion is paradoxical or to reject the seemingly acceptable premises. In this case the scientific paradox was mere illusion.

Through working with my students the fascinating discovery I made was that I was becoming more proficient using the logical principles I had learned, guided by the advice of Colyvan and the writing of many authors. In the case of the Mpemba Effect, I needed to separate the explanation of cooling from the explanation of freezing. Additionally, I chose to resist the temptation to accept blindly that every sample of water would take the same amount of time to freeze if the initial temperature was the same. I noted qualities of the water; dissolved gases, dissolved solutes, and motes, influence cooling and therefore could influence freezing.

I thought some writers had failed to acknowledge the need to separate the cooling and freezing processes and saw that they reported only on the time taken to freeze their water samples. The influence of the unpredictable, statistical nature of freezing time on supercooling was ignored. Esposito and others (2007, p. 3 Figure 1) and Auerbach (1995, p. 883 Figure 1), on the other hand, present results showing freezing temperatures as low as minus 8^{o}C and minus 12^{o}C respectively and Knight (op. cit.) reported temperatures as low as minus 20^{o}C. My students and I found that many water samples froze at or near zero degrees Celsius. When water undergoes the transition from liquid to solid the temperature of the water rapidly rises to zero degrees Celsius regardless of the sub-zero temperature at which the process of the change of state commences. (Esposito et al., 2007)

What my students and I found was that the temperature at which water freezes spontaneously is *not* predictable. This case of unpredictability, coupled with three freezing transition points, reported by Esposito and others at 6 degrees Celsius, 3.5 degrees Celsius and 1.3 degrees Celsius were all capable of delaying cooling and subsequent freezing of our water samples. We found the range of times taken to freeze water samples was very large, Auerbach (op. cit. fig. 1.) reports ranges of 200-560 seconds for hot and 170-250 seconds for cold samples. Auerbach concluded that, if individual samples of water are compared, there ought be a statistically significant number of occasions when the cooling of hot water samples in the absence of dramatic supercooling will lead to reduced freezing times, compared with samples of cold water that have undergone significant supercooling prior to freezing.

Truthfulness

To my surprise and delight, my students had shown me that the Mpemba Effect was an illusion because the premises upon which the logic was based were unacceptable, and the conclusion, that hot water freezing before cold water, was not paradoxical. The journal, *Physica A,* accepted the manuscript of Esposito and others (2007) which corroborates this finding.

When my students compared individual samples, the illusion appeared genuine to them, it was due to the probability of turning up counter-intuitive observations caused by supercooling. Auerbach (1995, p. 884) reports that statistically, if their own experiments had been carried out in pairs, then in 19 out of 36 samples exposed to temperatures between minus 5^{o}C and minus 8^{o}C would show the Mpemba Effect.

My students' and Osborne's technician's experiments ambiguously turned up, just as often as not, observations that were congruent with Newtonian cooling, reinforcing their almost overwhelming desire to repeat their experiments until they 'got it right'.

My novice students and Osborne's technician blamed poor experimental procedures for what they perceived as an occasional counter-intuitive result. My advanced students used my guiding principles of logical analysis, derived from Colyvan's advice and Brewer and Chinn's seven responses and were able to design experiments challenging the underlying assumptions and Erasto Mpemba's paradoxical conclusion.

It was a struggle for me to encourage my students to examine their assumptions about the cooling and freezing processes but I *was* able to encourage them to analyse explicitly the anomalous data using the, 'seven possible responses of students to anomalous data' suggested by Brewer and Chinn (1994). When I directed my students who faced anomalous results toward the practice of logical analysis, progress was assured. My students and I chose to adjust our 'A' theory accommodating the previously unknown, large influence of supercooling. Our theory was adjusted. Consequently, we no longer found the freezing of samples of hot water occasionally preceding the freezing of samples of cold water to be, in any way, unacceptable or paradoxical.

In the case of Erasto Mpemba's Effect, guided by Sainsbury's three paradox resolution strategies — reject the logic, reject that the conclusion is paradoxical or reject the seemingly acceptable premises, our naïve assumptions made way for more complex sophisticated and helpful assumptions. We were now able to believe that the conclusion we initially viewed as unacceptably paradoxical was rationally plausible and consistent with our new theoretical explanations.

Students like Jon and Doug brought their tools of logic acquired by studying paradoxes such Hempel's Ravens and the Barber's Paradox to the Mpemba Effect and saw through the illusion that had temporarily obscured their view and understood better science's truthfulness. In 2012, Nikola Bregović (Bregović, 2012) was awarded first place in the Royal Society of Chemistry's (R.S.C.) competition to resolve and explain the Mpemba Paradox. The R.S.C. received twenty five thousand entries.

My hope for my students is that they all come to believe—not in the dogmatic acceptance of the *truth of science*—but instead to believe in a science nevertheless blessed with an underlying *truthfulness* capable of being discovered by teachers, and students of courage like young Erasto Mpemba.

Chapter 4 – The Essence of Paradox

> The paradoxes also constitute a radical challenge to the rationality of human thinking: they are items about which it is difficult to say anything comprehensive without ourselves falling into contradiction (p. 239).

It seemed pertinent to begin, a rendering of paradox, with a line from John L. Mackie's seminal work (1973), *Truth, Probability and Paradox*,

The struggle to overcome this seemingly insurmountable yet apparently tractable barrier of finding an unambiguous definition was my major struggle. It is a struggle that I will endeavour to report in this chapter.

Synonyms

William Poundstone (1990) illustrates, through examination of the word 'labyrinth', a difficulty mentioned later in this chapter; the difficulty expressed by Georg Cantor of unambiguously defining a concept.

> In the Cretan language, a labyrinth could mean a mazelike building, a grotto or winding cave (a common feature of the Cretan landscape), or an inescapable dilemma in argument: a paradox (p. 161).

Similarly, in English many meanings for the word paradox exist in the literature and although my list, that follows, is by no means complete it does represent those English words that are in common usage: riddle, anomaly, antinomy (sometimes confused by the typesetters with elemental metallic antimony), puzzle, contradiction, conundrum, inconsistency, ambiguity, labyrinth, dilemma, and mock encomia. Although this list is not exhaustive, it contains many words in frequent use in scholarly writings, with the exception of mock encomia, which I'll report on later, used only in connection with ancient and Renaissance literature.

More telling perhaps than the individual words is the phrase, 'It is all Greek to me'. The ancient Greeks may have been the first to attempt a formal analysis of paradoxes, but paradoxes have always existed, my own children can attest to that fact. When my eldest son was two years old he asked, "Where did the first pea seed come from?" He clearly identifies a paradox as something he has found to be puzzling.

I attempt an analysis of the concept of *paradox* by utilising binary opposites, presented in Figure 1 below. *Epistēmē,* or true knowledge, arises from the resultant tension between these opposites.

J.S. Mill (1973) explains,

> *contrariorum eadem est scientia*…we never really know what a thing is, unless we are also able to give a sufficient account of its opposite (p. 735).

true	false
logical	illogical
acceptable	unacceptable
agreement	contradiction
intuitive	counterintuitive
plausible	implausible
apparent	imperceptible

Figure 1 - Binary pairs I use to analyse the concept 'Paradox'

My application of the use of one of the binary pairs always implies the denial of its opposite. I only use one of each binary pair; other authors attempting to outline the concept of paradox similarly use only one.

In addition to the pairs of binary opposites, to make sense of the logic involved in the paradoxes it was necessary for me to identify key terms of logical analysis. Knowledge of the language of logic was necessary for me to comprehend paradox construction, analysis and, resolution and I found that Figure 2 represented the minimum that I required:

antecedent	what follows the 'if' in a conditional
conclusion	the part of an inference for which reasons are given
consequent	what follows the 'then' in a conditional
inference	a piece of reasoning, where premises are given as reasons for a conclusion
premise	the part of an inference that gives reasons
valid	applies to an inference in which the premises really do provide a reason of some kind

Figure 2 - The language of paradox construction (From Priest, 2000, pp. 111-114)

Lexical Definitions

The etymological root of the word paradox is Greek, from the words, *para*, meaning beyond or contrary to, and *doxa*, meaning received opinion, belief, convention or current thinking. In Greek philosophy, the word *doxa* is often juxtaposed with *episteme* (true knowledge) adding yet another layer of complexity to paradox's meaning, suggesting perhaps that the development of knowledge — doxa, paradox, episteme.

According to Mardy Grothe (2004) the word paradox was introduced into the English language around the middle of the sixteenth century,

> ...one of the definitions of the word paradox: A statement that seems self-contradictory, false, or absurd but is nonetheless well-founded and true. The word shows up for the first time in English in 1540, a hundred years before the appearance of the word oxymoron. Paradox also comes from the Greek words, para meaning "beyond" and doxa meaning "opinion." Literally, it means "beyond opinion," but it originally conveyed the sense of "being beyond the pale of current opinion" or "contrary to current thinking." In the early days it had a negative connotation, suggesting something that was fantastically unbelievable or even heretical…Over time, the word gradually took on today's more favourable connotation — something that is true even though it may look false (p. 4).

What is interesting about Grothe's understanding is he has identified a positive connotation, which is contrary to what I have come to see as the dominant public opinion. Grothe's view is apparently in support of his thesis about oxymora, that is they stretch our minds and expand our thinking. Certainly, ancient philosophers engaged in paradoxical discourse.

I my opinion, Grothe himself does not see the view that a paradox might exist, when something is false even though it may appear true.

One needs look no further than the replacement of any falsified scientific claim. As evidence surfaces, which is contrary to expectation, scientific claims or perhaps paradigms take on a paradoxical appearance. In such a case, what was, previously, evidently true, and *not* simply apparently true, has been shown to be false.

This notion, opposed to that expressed by Grothe, is supported in the literature by Kleiner and Movshovitz-Hadar (1994) who state,

> A paradox has been described as truth standing on its head to attract attention.

Initially a narrow definition that is later broadened when they say,

> We will use the term “paradox” in a broad sense to mean an inconsistency, a counterexample to widely held notions, a misconception, a true statement that seems to be false, or a false statement that seems to be true (p. 963).

Kleiner and Movshovitz-Hadar’s understanding of paradox would appear to be derived from Blumenthal’s (1940), although they quote Blumenthal for a separate purpose. In his 1940 paper, Blumenthal conceptualised paradox in this way,

> More precisely, an assertion will be called a paradox provided it is seemingly contradictory or opposed to common sense. Thus, a paradox may be (1) a true statement that seems to be false, or (2) a false statement that seems to be true. This makes, to be sure, the labelling of an assertion as paradoxical a purely subjective matter—a kind of test of an individual’s sophistication. This is as it should be. To the omniscient there are no paradoxes! (p. 346).

The origin of the English language derivation of the word paradox, during the Renaissance, is likely due to the awareness of Italian and French serio-comic literature, for example, Ortensio Lando’s *Paradossi* published in 1543 and Charles Estienne’s *Paradoxes* published in 1553. I note that in Hugh Roberts’ (2004) critique of the role of the ancient Greek Cynics in mid-sixteenth century texts, that Erasmus of Rotterdam, or *Disiderius* as he was known, wrote a letter to Thomas More in 1510 in which he apologises for his literary style in his pamphlet, *The Praise of Folly* which invokes paradoxes or mock encomia, Roberts says, “Erasmus cites mock encomia by Isocrates, Seneca, Plutarch and Lucian, among others, as antecedents” (p. 459). This was, however, not in

English and it wasn't until 1549 that the pamphlet was translated. (van Loon, 1942)

The word paradox was therefore being constructed conceptually prior to the establishment of an English word equivalent. (Cf. Findlen, 1990)

According to Hugh Roberts (op. cit.),

> The Cynics, most famously represented by Diogenes of Sinope, constituted the most paradoxical school of ancient philosophy, since they devoted their lives to challenging convention (*doxa*) through serio-comic performance. Diogenes of Sinope (4th Century B.C.) as opposed to Diogenes Laertius (3rd Century A.D.) was a Dog (Cynic) like no other, …defecating, copulating, and masturbating in public (p. 459).

Diogenes sort to replace the, "...corrupt currency of convention…" by, as Roberts puts it, "...making the performance of acts designed to confound everyday norms and values…" (pp. 459-460). It was this function of paradox that Erasmus called upon, in the letter to Thomas More prefacing his 1510 essay titled, *The Praise of Folly*, to ameliorate readers' reactions to the shocking confrontation.

In the twentieth century, both Willard Van Orman Quine's 1961 essay, *The Ways of Paradox* (originally published, W.V.O.Quine, *Paradox*, Scientific American, vol. 206, 1962) and L.M. Blumenthal's (1940) *A Paradox, a Paradox, a Most Ingenious Paradox* call upon Gilbert and Sullivan's *Pirates of Penzance* to publicly illuminate paradox utilising their contemporary media. Blumenthal's use, unlike Quine's use, exposes the paradoxical underbelly without resorting, unnecessarily for his audience, to generalised mathematical representation. Blumenthal (1940) writes,

> Frederic, the simple, artless hero of Gilbert and Sullivan's operetta, 'Pirates of Penzance', shared with most individuals an interest in paradoxes. Indentured when a lad to a pirate instead of a pilot by a nurse somewhat hard of hearing, Frederic has attained his majority when the play opens and believes himself free to abandon the vile life to which he was so inadvertently delivered. But a technicality dashes

> his hopes, for the luckless boy was born on the twenty-ninth of February and the indentures bound him to the pirates until his twenty-first birthday. Confronted with this news, it is the paradox involved rather than the wrecking of his plans that engages his attention, and he exclaims:
>
> > "How quaint the ways of paradox!
> > At common sense she gaily mocks!
> > Though counting in the usual way,
> > Years twenty-one I've been alive,
> > Yet, reckoning by my natal day,
> > I am a little boy of five!"
>
> As there are mathematical theorems that also mock at common sense, are these paradoxes in mathematics, and, if so, can some, the most remarkable of them, be appreciated by those who are without an extensive mathematical education? These questions admit, I believe, an affirmative answer, but first let us be quite clear about the word "paradox." This word is derived from παρα "contrary to" and δόξα "opinion," and I shall use it in almost exactly this sense (p. 346).

Quine's purpose for the use of *Pirates of Penzance*, like Blumenthal's, is to juxtapose the average person's 'absurd' notion of paradox with a more rigorous, scholarly notion. Blumenthal's identification of a public definition of paradox is useful because the statement; "opposed to common sense," is a theme often repeated in the literature and deserving of further comment as this allusion is called upon in later twenty-first century definitions. Blumenthal, additionally, reiterates the sophistic nature of paradox I claim is prevalent in Western philosophical discourse.

Within the medical discipline, what is referred to as Sherman's Paradox, is a good illustration of, what I see is, the sophistic nature of paradox.

Ernst-L. Winnacker (1993) reports the following about Sherman's Paradox,

> A common feature however of (almost) all known hereditary diseases is their stable inheritance once a mutation has established itself. Thus, within an afflicted family the courses of a disease will not differ significantly among parents and their children. As is so often the case, exceptions should prove the rule. Well, maybe not in this case! Human geneticists have been aware for some time of a number of genetic diseases, which do not fit in with what was mentioned above. There appear

> to be cases in which the severity of the disease changes from generation to generation, in most cases becoming more severe. It is almost as if an initial mutation served as a basis for more and more new genetic alterations. As no explanation for this phenomenon was available, this particular situation in which the health risk of a person depends on his or her position in a pedigree was referred to as Sherman's paradox (p. 1415).

Winnacker has indicated the usual route that paradox finds a foothold in what Kuhn (1962, p. 10) would call, "normal science". Here we have an unexplained phenomenon; one that seemingly defies explanation, and is unacceptable; within the existing framework of understanding, which nevertheless was seen as solvable, and in the case of Sherman's Paradox satisfactorily resolved in 1993.

Sherman's Paradox was resolved by locating a gene with great instability at the end of the short arm on chromosome 4. The number of codon (3 nucleotide sequences) repetitions correlated with the age of onset of Huntington's chorea and the diseases severity. The example of Sherman's Paradox demonstrates the way the word paradox is used as a label for anomalous, *seemingly* implausible observations.

At the time of publication of Winnacker's article four other genetic diseases had been identified, that were explained by codon (tri-nucleotide) instability (Cf. Winnacker, 1993, p. 1417).

Students of science also tend toward falsely labelling anomalous, in my students' words, "weird", observations as paradoxical as they struggle to conceptually accommodate the new and the old. John Rastovac and David Slavsky's (1986) comments indicate that for students of science, as well as the professional scientist, it appears, the average person's naïve definition of paradox is used. Rastovac and Slavsky write,

> When faced with new concepts, students frequently express misconceptions about them. Occasionally the misconception stems from the use of a seemingly logical

> reasoning process after identifying and using the wrong variables. Because of the logic, the erroneous conclusion seems paradoxical to the students (p. 118).

Where Rastovac and Slavsky use the word, "variables" they implicate the premises on which the students' logical deduction is based. The illustration they use in their article is their students' false conclusion that seasonal temperature variation is due to the Earth-Sun distance, based upon their acceptable premise that the closer one is to a heat source the hotter it becomes. Rastovac and Slavsky's students conclude that summer is caused by being closer to the sun. This conclusion would imply that summer should come to Northern and Southern Hemispheres concurrently. Students know that the Northern and Southern Hemispheres experience summer in different months of the year and so Rastovac and Slavsky's students found this knowledge conflicted with their proximity premise (hypothesis), and therefore they found that paradoxical. The conclusion of the students is logically reasoned and yet is nevertheless invalid because it is based on their false premise that seasonal temperature variation is due to Earth-Sun distance.

A conclusion is deductively valid if and only if the premise or premises upon which the conclusion is based is actually true. *Something* being logical and yet invalid defied my students' common sense.

Paradox and Common Sense

The contradiction of common sense is a theme that appears throughout the history of the development and use of the word paradox. John Barrow (1999), writes,

> The word 'paradox' is a synthesis to [sic] Greek words, *para*, beyond, and *doxos*, belief. It has come to have a variety of meanings: something which appears contradictory but which is, in fact, true; something which appears true but which is, in fact, contradictory; or a harmless chain of deductions from a self-evident starting point which leads to a contradiction (p. 12).

Both Barrow, in his book, *Impossibility: The Limits of Science and the Science of Limits*, and Blumenthal (1940) are of the opinion that nature is consistent and therefore paradoxes are a consequence of mistaken reasoning or inadequate knowledge. Barrow (op.cit.) claims, “The consistency of Nature must mean that in some sense there are no true paradoxes (or, more weakly, perhaps that none are observable)” (p. 197).

A word of caution is required if one were to accept the average person’s interpretation of the word paradox. Such a cautionary note, regarding blind acceptance, is offered by Michael Clark (2002), “Etymologically the paradoxical is what is contrary to (*para*) received opinion or belief (*doxa*).” However, continues Clark, “We can’t simply say there is a paradox whenever there are arguments for incompatible conclusions, or every matter of controversy would be a matter of paradox” (p. 132 & 134). Unfortunately, it would appear that the average person’s ignores Clark’s advice and their interpretation really does reflect Clark’s antithesis.

Brian Silver (1998) in *The Ascent of Science* makes a similar point to Clark about the difference between paradox and common puzzlement. In reference to the seriously paradoxical Quantum Theory, Silver says,

> The first European to see a giraffe was probably astounded. But the giraffe was merely unexpected; it was not incomprehensible. There are some aspects of quantum mechanics that not only defy common experience they defy reason (p. 378).

The French Paradox is a good example of a contemporary controversy that was unexpected that will further the argument that the average person confuses paradox with puzzlement. The capacity of the French, particularly women, to consume high fat, high energy foods and alcoholic beverages, whilst possessing reduced levels of societal obesity and concomitant cardiovascular disease has puzzled American Society. This puzzlement has resulted in the publication of a plethora of books and articles about the reported counter-intuitive observation of Frenchwomen’s capacity for weight control in spite of their purported epicurean lifestyle.

An examination of the total energy intake of the average American citizen and the average French *bon vivant* would reveal the premise, of high energy intake by French women is false. French women may eat energy dense food but they evidently, according to low societal obesity, eat less than Americans.

Another example, this time in a science context, of prematurely labelling contradictory evidence paradoxical emerged at the beginning of the twentieth century as a consequence of Einstein's Relativity Theory. In 1927, Luise Lange writes,

> At superficial thought the very first consequence of the Lorentz transformation may appear paradoxical: that of two systems in uniform relative motion each one finds its own clocks to go faster than those of the other (p. 22).

When this consequence of Einstein's Relativity Theory emerged, it naturally was used as ammunition to argue against relativity's validity. Lange argues that, "Yet, of course, there is no paradox in this." (loc. cit.) Lange formulated a convincing argument in support of his contention that there was no paradox on the basis that the conclusion contravened common sense understanding. He structures his *reductio ad absurdum* argument in such a way as to generate a pair of contradictory conclusions based on plausible premises and then proceeds to argue absolute time is deductively invalid.

Lange reported that this purported paradoxical consequence of the Lorentz transformation was initially called Langevin's Paradox after Paul Langevin, a French Physicist who presented his solution at a meeting in Boulogne in 1911. Langevin's Paradox is now known as the Twin Paradox.

The counterintuitive consequence of the Twin Paradox, the travelling twin being younger than the stay at home twin, was validated by empirical evidence obtained utilising caesium clocks in 1972. The common sense view that 'time is universal' is false. Time is relative. Clearly humankind's reliance on common sense is fraught with danger.

The emergence of paradoxes within the sciences as a consequence of mistaken reasoning or poor observation is a view that can be traced to the scientific revolution of the Renaissance. Early scientists considered counterintuitive observations a fair indication of something going awry.

In the late seventeenth century Francis Roberts (1693) writes,

> As some truths (like the Axiomes of Geometry and Metaphysics) are self-evident at the first view, so there are others no less certain in their Foundation, that have a very different Aspect, and without a strict and careful Examination rather seem repugnant. We may find Instances of this kind in most Sciences.

Roberts identified an example of an ‘Aspect’ that seems repugnant in astronomy, “In Astronomy, that at the Barbadoes (and other places between the Line and Tropick) the Sun, part of the Year, comes twice in a morning to some Points of the Compass.” His assessment of this instance led him to conclude, “...these Speculations, as they are generally pleasant, so they may also be of good use to warn us of the Mistakes we are liable to, by careless and superficial reasoning” (pp. 677-678).

Mark Sainsbury’s (1995) conceptualisation of paradox may well be the most recognised and widely accepted version in philosophical use, as attested by the seventh printing of the second edition of his book, *Paradoxes*. Sainsbury states what he understands a paradox to be,

> This is what I understand by a paradox: an apparently unacceptable conclusion derived by apparently acceptable reasoning from apparently acceptable premises. Appearances have to deceive, since the acceptable cannot lead by acceptable steps to the unacceptable. So generally, we have a choice: either the conclusion is not really unacceptable, or else the starting point, or the reasoning, has some non-obvious flaw (p. 1).

Sainsbury adheres to the orthodox view that nature is consistent and therefore the origin of the paradoxes, even the intractable kind, is human, either by means of flawed reasoning or by means of failure to accept some manifest truth, leading to false premises; or the counterintuitive conclusion, one finds unacceptable or implausible, is actually true. Sainsbury, unlike Graham Priest, does not indulge the possibility that the logic being used to reason the argument is in need of revision.

It is prudent to point out that flawed reasoning within a system such as Aristotelian logic (A-logic) and a flawed reasoning system are distinct.

What would a new logic look like? Priest's dialetheism is the only serious attempt at a new logic.

Priest's dialetheism, which rejects the law of contradiction, would be insufficient if it can be demonstrated that dialetheism too leads to instances of contradiction. I will call these D-logic paradoxes to differentiate A-logic (Aristotelian) paradoxes such as The Liar Paradox.

The Liar Paradox presents us with a situation in which, analysed by A-logic the statement, 'I am lying' seems paradoxical because of the implication that the utterer is both a liar and a truth teller and this is presently implausible because the basic tenet of A-logic, known as the law of contradiction, A and ¬A (the opposite of A) cannot both be true.

Quine maintains a rigorously anti-dialetheist stance, a seemingly necessary role for a member of the old guard. Priest (1995) implores his readers in a grievance directed at Quine's comment, "…that someone who maintains that a contradiction might be true just does not know what they are talking about," by drawing on a comparison with the old guard's reluctance to accept the paradoxical consequences of relativity theory when he says that Quine's comment is, "...exactly analogous to a Newtonian physicist complaining that someone who holds that time might run at different rates in different frames of reference just does not know what they are talking about" (p. 4).

Priest is suggesting, dare I say, that to ignore the fourth possible cause of the origin of paradoxes would be like Galileo's inquisitors refusing to view the Jovian moons. Priest's difficulty is however to overcome the maxim that from a contradiction any conclusion is derivable.

Willard V.O. Quine is widely recognised as a significant figure in the twentieth century exploration of paradoxes. In *The Ways of Paradox* (1966), Quine defines a paradox as follows:

> May we say in general, then, that a paradox is just any conclusion that at first sounds absurd but that has an argument to sustain it? In the end, I think this account stands up pretty well. But it leaves much unsaid. The argument that sustains a paradox may expose the absurdity of a buried premise or of some preconception previously reckoned as central to a physical theory, to mathematics, or to the thinking process. Catastrophe may lurk, therefore, in the most innocent-seeming paradox.

Quine defines the word paradox by initially deconstructing the concept to identify three sub-sets of paradox based most assuredly on their ease of resolution but also on their logical form and causal agent.

Quine says,

> A veridical paradox packs a surprise, but the surprise quickly dissipates itself as we ponder the proof. A falsidical paradox packs a surprise, but it is seen as a false alarm when we solve the underlying fallacy. An antinomy, however packs a surprise that can be accommodated by nothing less than a repudiation of part of our conceptual heritage.

Quine identifies the need for a complete revision of our conceptual heritage in order to ameliorate the antinomies consequent to his present schemata.

> Revision of our conceptual scheme is not unprecedented. It happens in a small way with each advance in science, and it happens in a big way with the big advances, such as the Copernican revolution and the shift from Newtonian mechanics to Einstein's theory of relativity. We can hope in time even to get used to the biggest such changes and to find the new schemes natural. There was a time when the doctrine that the earth revolves around the sun was called the Copernican paradox, even by the men who accepted it (p. 1 & 9).

Willard Quine's book, *The Ways of Paradox and other essays: Revised and enlarged edition* (1976) demonstrates the ease with which paradoxical statements are generated for it contains the following, presumably unwittingly generated, paradoxical statement, “This book has been digitally reprinted. The content remains identical to that of previous printings,” a statement reminiscent of Theseus’ Ship Paradox. Quine’s first book appeared in 1966; his second edition was revised and enlarged by the addition of eight further essays in 1976. How can the two statements, “The content remains identical to that of previous printings” and “revised and enlarged edition” be consistent? Maybe Quine has succumbed to the lure of David Makinson’s Preface Paradox (1965, pp. 205-207). Raymond Smullyan (1986) engaged deliberately with paradox in his book titled , *This Book Needs No Title*. Roy Sorensen (2003) dedicated his book, “To those who never have a book dedicated to them”. In Quine’s case I believe his statement was purely accidental.

Quine uses the terms ‘veridical’ (truthful) to separate the paradoxes that Sainsbury (1995) refers to as “weak” from ‘antinomy’, paradoxes Sainsbury refers to as “cataclysmic”, which in Sainsbury’s words are a class of paradoxes capable of sending, “…seismic shudders through a wide region of thought…” (pp. 1-2). Quine reserves the term ‘antinomy’ for those “cataclysmic paradoxes”, such as The Liar Paradox.

The word antinomy was a legal term, which translated more or less directly as, “against the law.” (Agostini, 1980, p. 91) The antinomies of Kant are not really constituted within the cataclysmic class and therefore Quine’s use of ‘antinomy’ appears to be out of reverence for Kant and as a consequence his intention to clarify the word paradox has misfired and instead contributes to a lack of an unambiguous definition, even from within the cognoscenti.

In my opinion, Sainsbury’s definition referred to previously is unambiguous. Sainsbury’s only concession to ambiguity comes when he makes reference to the conclusion of Roy Sorensen. In 1988 Sorensen stated, that all paradoxes may conceal, “a master cognitive flaw” suggesting that the many paradoxes may be, the many signs of his master flaw.

In 2003, Sorensen defined paradoxes this way, “Paradoxes are questions (or in some cases, pseudo-questions) that suspend us between *too many* good answers." Sorensen goes on to say, "I take paradoxes to be a species of riddle" (p. xii & 3). Sorensen quotes Gareth Matthews (1974) who, "…defines a paradox as a statement that conflicts with a conceptual truth," in recognition of the tentative nature of the truth claims that are conflicted, in part, to acknowledge the possibility of his "master cognitive flaw" (p. 6).

This notion of truth creates yet another impasse for the paradox scholar.

In 1931, Alfred Tarski wrote,

> For although the meaning of the term 'true sentence' in colloquial language seems to be quite clear and intelligible, all attempts to define this meaning more precisely have hitherto been fruitless, and many investigations in which this term has been used and which started with apparently evident premises have often led to paradoxes and antinomies (for which, however, a more or less satisfactory solution has been found) (1956, p. 152).

Tarski's hierarchy of truth precludes the Liar Paradox by arguing that a statement is true if and only if what it is claiming is actually true. (Cf. Etchemendy, 1988; Kripke, 1975; Mackie, 1973; Sainsbury, 1995) Although this definition of truth may seem rather absurd, the impact of his definition of truth has implications for logical paradoxes, paradoxes such as The Liar Paradox, known as semantic paradoxes. These semantic paradoxes Ryszard Zuber (1975) defines as, "...presuppositions whose failure to hold produces the paradoxical consequences of constructions known as semantical antinomies" (p. 261). The Liar Paradox and set-theoretic paradoxes, such as Russell's Set Paradox are classic examples of semantic paradox; they are unavoidably entangled with the concept of truth.

The impact of Bertrand Russell and in particular his Set Paradox is highly significant according to Gregory Chaitin (2002) "Russell is key because he discovered some disturbing paradoxes in logic itself. That is, he found cases where reasoning that seems to be sound leads to contradictions" (p. 165).

The implication of Tarski's theory of truth, for epistemology, is sensed by Karl Popper. Popper (1955) writes,

> The proper epistemological question is not one about sources; rather, we ask whether the assertion made is true—that is to say, whether it agrees with the facts. (That we may operate, without getting involved in antinomies, with the idea of objective truth in the sense of correspondence to the facts, has been shown by the work of Alfred Tarski.) And we try to find this out, as well as we can, by examining or testing the assertion itself; either in a direct way, or by examining or testing its consequences (p. 27).

William Sandoval (2005) believes students' epistemological beliefs provide fertile ground for the critical examination of inquiry practices, he writes,

> I argue in this paper that a comparison of the research on students' epistemological beliefs and research on students' inquiry practices suggest a paradox: that students' practices of inquiry appear to share much with scientific practice but their expressed epistemological beliefs seem hopelessly naïve. The resolution of this paradox requires a shift in the way scientific epistemologies are conceptualized and studied (p. 635).

The students in Sandoval's study appeared to lack the tools for critically examining their own knowledge claims. The 'tripartite account' of belief, justification and truth provide the basic philosophical tools for students to examine their knowledge claims.

Again, truth is implicated in all definitions of paradox. In the writing of John Mackie (1973) he uses the term "apparently" to qualify his definition of paradox,

> Typically, a paradox is an apparently sound proof of an unacceptable conclusion; in most, though not all, of ours the conclusion is unacceptable because it is self-contradictory. What we may call the reasoning within the paradox has two branches, and the conclusion of one branch contradicts that of the other (p. 238).

Mackie's insistent use of "apparently" avoids the irrationality of claiming a sound proof of an unacceptable conclusion from acceptable premises. His choice places the doubt, implicit in the definition, with the reasoning, avoiding the need to alter his existing epistemological paradigm.

The unwillingness of most paradox scholars to accept the challenge of finding Sorensen's, "master cognitive flaw" and, or following Quine's advice to revise, "...our conceptual scheme…" (op. cit.); is indicated by their choice and use of adjectival qualifiers.

In 1938, John Dewey failed Sorensen's challenge when in response to the Map of England Paradox; he asserts, "The second reason is connected with certain alleged paradoxes. There is the example of the self-representative series…The supposed paradox arises only when there is a shift from the existential to the conceptual." The Map of England Paradox presents the argument, that in order for the map of England to be complete, it must itself contain, said map of England, *ad infinitum*. The view expressed by Dewey, that the paradox arises out of the shift from the existential to the conceptual, is shared by Karl Popper. (Cf. Popper, 1974)

In response to the Barber Paradox, Dewey is again dismissive, "There is also the alleged paradox in the case of the soldier barber…" (pp. 363-364). Finally, Dewey's use of the word 'notorious', regarding the paradox of the liar, demonstrates the pervasiveness of a dismissive attitude toward the genuine status of paradox, "A similar mixing of propositions of two different logical forms is found in the notorious case of Epimenides and Cretans as liars" (p. 383). In each case cited, Dewey rejects the authenticity of paradox by avoiding the paradoxes and failing to give recognition to Sainsbury's criterion of demarcation, Dewey placing the weak, Barber Paradox on an equal footing with the cataclysmic Liar Paradox.

The Oxford English Dictionary boldly declares paradoxes to be, "A statement or tenet contrary to received opinion or expectation." This definition casts a wide net and admirably reflects the status of paradox in the wider community. Careful examination of the Oxford English Dictionary through history reveals little change to this definition over the centuries.

J.D. Workman (1969) claims, for the word paradox, a longer pedigree back to Cicero and also contrasts common usage, literary usage and an ill-defined alternative "modern" usage,

> Possibly one reason why the paradox has attracted so little systematic attention as a literary phenomenon in modern times is that here too familiarity has bred contempt. After all, everyone knows, or thinks he does, what constitutes a paradox: It is quite simply "a thing which seemeth strange" (Schilder, p. 52). The term is widely if somewhat loosely used in critical writing. The dictionary definition of "a statement or tenet contrary to received opinion or belief" has not changed appreciably since Cicero's day ("admirabilia contraque opinionem omnium"), 6 although this must be qualified with the secondary meaning, currently perhaps more significant than the original one: a statement "seemingly self-contradictory or absurd, though possibly well founded or essentially true." It has been pointed out that most additions to knowledge are considered paradoxical to begin with, e.g., the Copernican theory of the universe, Darwin's natural selection, Einstein's relativity, etc" (p. 702). Cicero, however, referred to the paradoxes of the Megarian, Eubilides, as "far-fetched and pointed sophisms (Cicero, Academic Questions, Cited in Sorensen, 2003, p. 88).

The term 'sophism', used by Cicero, is highly insulting and reserved only for comment regarding false or vicious reasoning; it is illuminated by the phrase, 'the cobwebs of sophistry.' The Sophists were also members of a tradition fathered by Protagoras. Followers of Protagoras would argue on behalf of their wealthy Athenian aristocrat clients in a litigious Greece. Protagoras will later provide an example of paradox, the Protagoras-Euathlus Paradox (Cf. Clark, 2002, pp. 96-98; Sorensen, 2003, pp. 62-63). The solution of the Protagoras-Euathlus Paradox by Gottfried Leibniz in his doctoral dissertation illustrates the temporal nature of paradox enunciated with reference to Dewey, Quine, and others.

Paradox and Literature

The use of the word paradox within works of literature is significant because it helps mould the average person's construction of the word. Giles Milton (2001) in his book, *In Search of Sir John Mandeville: The Riddle and the*

Knight writes about the influence of Mandeville's one and only book, *The Travels*, as a significant influence on writers of the Middle Ages. Milton says,

> The writers and poets of the Middle Ages loved the riddles of their Saxon forebears. They indulged in clever word plays, wrote alliterative verses, sang roundels, and wallowed in folklore. A handful of critics suggested that Mandeville's book, too, concealed a hidden message; that the entire 'Travels' had been composed as an extended riddle or allegory whose meaning has long ago been lost (p. 10).

Milton suggests Mandeville uses metaphor or parable to describe that which cannot be described, which in turn reminded me of my previously cited quotation from Agostini (1980) "Finding an unambiguous definition for a concept has always been a fundamental problem" (p. 102). Because of his background in mathematics I assume Agostini is paraphrasing Georg Cantor's (1880) reflection on set theory that, "All concepts are ambiguous. Set theory would be no different."

Agostini (op. cit.) defined paradox as, "...problems or results that contradicted the evidence or belied ordinary intuition and were therefore somewhat surprising." (p. 91)

The metaphoric and or ironic use of paradoxical language is commonplace in literature.

In 1894, Lewis Carroll (The pseudonym of Reverend Charles Dodgson) concocted a derivation of a logical paradox that questioned the rationality of logic and the writing of Bertrand Russell continued to question logic in the beginning of the twentieth century.

Carroll's literary style and eloquence has undoubtedly been a significant factor in the development of the public construction of paradox in the same way that Russell's style and eloquence developed the concept within the mathematical and philosophical communities.

Carroll introduces the logic device known as *reductio ad absurdum*, a principle mechanism for the falsification of scientific knowledge (e.g. Michelson/Morley 1887 experiment) and 'verification', or mathematical proof (e.g. Euclid's proof of the irrationality of √2). In a fictitious story regarding the proof of a logically certain event, Carroll (op. cit.) writes,

> "Carr's certain to be in," said Uncle Joe. "I'll bet you sixpence he isn't!" said I. "Keep your bets for your betters," said Uncle Joe. "I mean"—he hurried on, seeing by the grin on my face what a slip he'd made—"I mean I can prove it, logically. It isn't a matter of chance." "Prove it logically!" sneered Uncle Jim. "Fire away, then! I defy you to do it!" "For the sake of argument," Uncle Joe began, "Let us assume Carr to be out. And let us see what that assumption would lead to. I'm going to do this by Reductio ad Absurdum.

Carroll extols his reader:

> I hope that some of the readers of MIND who take an interest in logic will assist in clearing up these curious difficulties (p. 436 & 438).

Carroll's fiction, the Barber Shop Paradox, as distinct from Russell's Barber Paradox, is based upon the premise that if Allen is out Brown is out. Brown goes with Allen because of a recent fever suffered by Allen. Carroll's character, "Uncle Joe", assumes that Carr is out and the logic develops the contradictory pair of conclusions that Brown is both out and in to then assert that Carr must be in because the assumption that he was out led to a logically developed contradiction.

Brown must be in because if Carr and Allen were out he would need to be in to mind the shop. Brown must be out because if Allen is out, Brown is out because Brown always goes out with Allen since his illness. The conclusion that Brown is out *and* Brown is in is contradictory, hence Carr must be in. Carroll uses the logical generation of a contradiction to assert that Carr must be in; his use of a plausible situation allows the average person the chance to play Theseus in the Cretan Labyrinth. The paradox remains because Carr never being able to go out is ridiculous as Carr can go out provided that Allen remains.

Paradox and Induction

Induction as opposed to deduction presents the logician with a unique difficulty. In deductive reasoning it is possible to express a sound proof that is neat and tidy within the system of which it is part. A logically expressed deductive conclusion does not necessarily have to be true, a point made earlier, yet it is either absolutely valid (truthful) or absolutely invalid (false), whereas an inductively reasoned conclusion cannot be known to be either true or false, yet it can be claimed to be valid or invalid. Statistics is the usual source of validation for our inductive conclusions.

Karl Popper (1972) places an historical appreciation of induction at the feet of Socrates and Aristotle. Karl Popper writes,

> Aristotle, and also Bacon, I wish to suggest, meant by 'induction' not so much the inferring of universal laws from particular observed instances as a method by which we are guided to the point whence we can intuit or perceive the essence or the true nature of a thing.[7] But this, as we have seen, is precisely the aim of Socrates' maieutic: its aim is to help or lead us to anamnēsis; and anamnēsis is the power of seeing the true nature or essence of a thing, the nature or essence with which we were acquainted before birth, before our fall from grace. Thus the aims of the two, maieutic and induction, are the same. (Incidentally, Aristotle taught that the result of an induction—the intuition of the essence—was to be expressed by a definition of that essence.) Now let us look more closely at the two procedures. The maieutic art of Socrates consists, essentially, in asking questions designed to destroy prejudices; false beliefs which are often traditional or fashionable beliefs; false answers, given in the spirit of ignorant cocksureness. Socrates himself does not pretend to know. His attitude is described by Aristotle in the words, 'Socrates raised questions but gave no answers; for he confessed that he did not know.' (Sophist. El., 183b7; cf. Theaetetus, 150c-d, 157c, 161b.) Thus Socrates' maieutic is not an art that aims at teaching any belief, but one that aims at purging or cleansing (cf. the allusion to the Amphidromia in Theaetetus 160e) the soul of its false beliefs, its seeming knowledge, its prejudices. It achieves this by teaching us to doubt our own convictions. Fundamentally the same procedure is part of Bacon's induction (pp. 12-13).

It was David Hume's understandings of inductive reasoning in his Treatise of Human Nature that led Popper on his quest for a Criterion of Demarcation, to separate meaningful from meaningless statements. Hume's concern was coupled to the need for inductive reasoning to be contingent upon an appeal to observational experience and that each appeal would lead to further appeals in an, "infinite regress". Infinite regressions fall within the purview of Sorites Paradoxes that invoke the logic of *modus ponendo ponens* (that of verifying the antecedent), where the conclusion for each argument becomes the premise for the following argument. In such arguments, it is possible to make a case for observationally invalid conclusions; an example of which is, 'A grain of rice is a heap'. (Cf. Sainsbury, 1995 The Paradox of the Heap)

In 1937, in his paper, '*Le Problème de la Verite*' (Theoria (Göteborg), vol. 3) Carl Hempel firmly plants the seed of paradox within inductive reasoning i.e. the scientific method (Cf. Langford, 1937). Although it is intuitively acceptable to the average person that inductive reasoning is logically valid, Hempel showed that not only was induction not logically valid, the claim also made by the likes of Hume and Popper, but, confirmation of general statements derived from inductive logic was also suspect. In the following example the average person would accept, as logically valid, the conclusion that, 'All metals expand when heated': Ten different metals are heated and are found to expand. The statement, 'All metals expand when heated' can be shown to be statistically valid but never logically valid.

In Hempel's (1945) *Studies in the Logic of Confirmation I.*, his stated objective was the logical analysis of confirmation. Hempel states,

> The defining characteristic of an empirical statement is its capability of being tested by a confrontation with experimental findings, i.e. with the results of suitable experiments or "focussed" observations. This feature distinguishes statements which have empirical content both from the statements of the formal sciences, logic and mathematics, which require no experiential test for their validation (p. 1).

The confrontation Hempel seeks is with the logical analysis of falsification promulgated by Karl Popper in *Logik der Forschung* (Popper, 1959).

Hempel (op. cit.) clearly enunciates the logical difficulties of induction in his paper, “Thus, any discussion of induction which refers to the establishment of general hypotheses on the strength of particular instances is fraught with all those logical difficulties—soon to be expounded—which beset the concept of confirmation” (pp. 3-4).

Hempel (op. cit.), like Popper (Cf. Logik der Forschung, 1935), shows that inductive reasoning cannot be logically determined:

> Recent logical analyses have made it increasingly clear that this way of conceiving the problem involves a misconception: While the process of invention by which scientific discoveries are made is as a rule psychologically guided and stimulated by antecedent knowledge of specific facts, its results are not logically determined by them; the way in which scientific hypotheses or theories are discovered cannot be mirrored in a set of general rules of inductive inference (p. 4).

In 1972, in reference to Hempel’s “infamous ravens”, Alfred Ayer wrote:

> This is not, indeed, a paradox in the sense that it yields a contradiction, but it does run counter to what we naturally think. We might not be so strict as to maintain that only the discovery of black ravens can confirm the hypothesis that all ravens are black – for instance, the pigmentation of birds of other species might be held to be relevant – but certainly we should not ordinarily take this hypothesis to be confirmed by the fact that I have a white handkerchief in my pocket, or a black fountain-pen. Such facts as these, we should say, are obviously irrelevant (pp. 67-68).

The year 1972 is 35 years after the publication of Hempel’s original paper in 1937 and Hempel’s Ravens are still providing difficulties to Ayer, an eminent philosopher and logician, and to many of his contemporaries such as Israel Scheffler.

Scheffler (1963) speaks of the Paradoxes of Confirmation this way,

> Now these “paradoxes” are not formal contradictions; they do not render their containing theories inconsistent. Rather, they represent a violation of our initial

> sense of the range of positive instances. A construction containing them thus collides with our intuitions in the matter (p. 260).

Hempel (op. cit.) thought:

> Perhaps the impression of the paradoxical character of the cases discussed in the beginning of section 5 may be said to grow out of the feeling that the hypothesis that all ravens are black is about ravens, and not about non-black things, nor about all things (p. 17).

'All ravens are black' is an hypothesis as well as being a generalised statement, already demonstrated to be impossible to logically substantiate by induction. Anything which is not black is by definition, not a raven. If I *claim* that to be called a raven a bird *must* be black there is no problem, unless I see an all-white bird, evidently a Tasmanian Forest Raven *Corvus tasmanicus*.

Linked with the impossible task of logical justification of inferences derived from inductive reasoning it would seem that Hempel's Ravens Paradox is no paradox at all; or at the very outside it may be considered falsidical, to use Quine's nomenclature. Hempel drew the same conclusion.

Hempel (1946) states,

> The general principle here illustrated together with its various consequences, which at first blush appear highly counter-intuitive, constitute the paradoxes of confirmation. In my article I tried to show that upon closer analysis the results thus arrived at prove to be reasonable, and that the impression of paradoxicality arises from a misguided intuition in the matter… (p. 79).

The abandonment of generalised statements would seem unlikely given mankind's propensity to hold on vigorously to individual generalised statements. The likelihood of complete abandonment would be tumultuous; however the abandonment of individual statements does occur and will continue to occur in the light of falsifying evidence, such as my own observation of a white raven.

Why is it that new paradigms in science, for example heliocentricity, are at first considered paradoxical and later straight-forward? Is it because of the epistemological framework of the persons considering the new paradoxical conclusions? If a person considered knowledge to be *truth*, then new findings, and there will inevitably be new scientific findings, must seem contradictory or paradoxical. To avoid this form of paradoxicality one must dispense with this view that knowledge is truth, and instead ask, as Popper does, do our assertions, our knowledge claims, have verisimilitude or *scientific truthfulness,* the sort of truthfulness claims that I was encouraging my students to make.

The longevity of the dialogue surrounding Hempel's Ravens may be due to an experience that is referred to by Bryan Bunch (1997), "Experience has shown, however, that when the results of reasoning and mathematics conflict with experience in the real world, there is probably a fallacy of some sort involved. As long as you do not know what the fallacy is, the situation is a *paradox*" (p. 2). When Ronald Giere (1970) presents Hempel's Ravens Paradox as, "The original paradox of confirmation may be illuminatingly presented as an explicitly inconsistent triad of plausible conditions on a purely qualitative, syntactical definition of confirmation" (p. 354), he forgot to turn on his torch.

Karl Popper (1959), in response to the notion that linguistic analysis is the true method of philosophy states,

> One such reason is the correct belief that logical paradoxes, like that of the liar ('I am now lying') or those found by Russell, Richard, and others, need the method of linguistic analysis for their solution, with its famous distinction between meaningful (or 'well-informed') and meaningless linguistic expressions. This correct belief is then combined with the mistaken belief that the traditional problems of philosophy arise from the attempt to solve philosophical paradoxes whose structure is analogous to that of logical paradoxes, so that the distinction between meaningful and meaningless talk must be of central importance for philosophy also. That this belief is mistaken can be shown very easily. It can be shown, in fact, by logical analysis. For this reveals that a certain kind of reflexivity

> or self-reference which is present in all logical paradoxes is absent from all the so-called philosophical paradoxes—even from Kant's antinomies (p. 17).

In Douglas Adams' (1988) fiction, *Dirk Gently's Holistic Detective Agency*, Professor Urban Chronotis, the Regius Professor of Chronology says to the central character Richard MacDuff,

> That isn't to say that if you get involved in a paradox a few things won't strike you as being very odd, but if you've got through life without that already happening to you, then I don't know which Universe you've been living in, but it isn't this one (p. 228).

Graham Priest (1995) has also propounded the persistence of paradox,

> Like the air in a partially inflated balloon, if the contradictions are pressed down at one point, they come up in another. One might call this the law of conservation of contradiction (p. 249).

The thought that, like momentum, paradoxes can be conserved, resisting any attempt at resolution is indicative of a need for a new voice. I had thought for some time that Graham Priest (op. cit.) with his dialetheism offered a new voice, albeit one that in his own words is, "so outrageous to the sensibility of modern philosophers" (p. 5). Immutability, like that which is granted A-logic, the concept of a species or the spatial distribution of Earth's continents when successfully refuted leads to the most astounding transformations of science, the same could be true for logic.

The limitations of Aristotelian logic (A-logic), indicated by logically generated contradictions, should necessitate further critical examination of logic's claimed immutability.

The similarities between the Western Philosophical tradition and the Eastern Philosophical tradition is illustrated by the number of authors dabbling in the Zen form. Raymond Smullyan (1986) asks,

> Is Zen paradoxical? In the last analysis, I believe the answer is no. Of course, the entire Zen literature abounds in paradox, but it seems to me that Zen-masters use

> paradox mainly as a technique to lead one to a state where the entire duality between paradox and non-paradox is transcended (p. 84).

The koan or Zen puzzle is described by Smullyan (op. cit.) as, "...a problem given by Zen-Masters which has no logical solution; its purpose is to force the realization of the futility of logic in dealing with ultimate reality" (p. 114). The koan is not a paradox, it is an oxymoron, the juxtaposition of opposites. I agree with Dale Cyphert (1998), who says, "A paradox is created, not through any ambiguity of syntax or semantic meaning, but by juxtaposing two irrefutably certain, logically perfect yet contradictory statements" (p. 88). Japanese Buddhists' aim for the koan is *Satori*, the word meaning 'enlightenment'. *Satori* is akin to Plato's *anamnēsis* (loc.cit.).

Some authors, for example Marianne Lewis and Gordon Dehler's (2000) link paradox and koan when they claim,

> Paradox denotes contradictory, mutually exclusive elements that exist simultaneously and for which no synthesis or choice is possible nor necessarily desirable (p. 708).

Although the Zen koan is not paradoxical and not intended to be resolved, merely contemplated, paradoxes can be resolved.

Paradox and Cognitive Conflict

The relationship between paradox and cognitive conflict is described by Nitsa Movshovitz-Hadar and Rina Hadass (1990),

> A cognitive conflict is strongly related to paradoxes. A paradox is created when two (or more) contradicting statements seem as if both are logically provable. Clearly, at least one of the statements must be false, and thus a flaw must exist in its proof. However as long as both statements seem convincing enough to impede a resolution on the part of a person facing them, this person is in a state of cognitive conflict. Such a conflict, between two competing ideas, is one of three types of cognitive conflicts defined by Sigel (1979). Cognitive conflict is usually a tense state. According to Berlyne (1960) it plays a major role in arousing, what he called, epistemic curiosity. An ordinary person has a strong incentive to relieve the

> conflict as soon as he or she can. Consequently it drives one to an intensive, and hopefully fruitful, activity of thinking, and of critical examination of existing knowledge. Resolving the cognitive conflict, a paradox presents, involves turning at least one of the proofs into a fallacy, by pinpointing the invalid reasoning, and thus ‘debugging’ it. Debugging, as Papert (1980) indicated, is a powerful mechanism in the process of learning (pp. 265-266).

It would seem from the remarks of Movshovitz-Hadar and Hadass, Papert and Berlyne, that studying paradoxes may provide an avenue for generating cognitive conflict, a necessary component in student learning. (Cf. Watson, 2002; Laburu, 2002; Kang, 2004; Lee, 2003; Sandoval, 1995 & Biggs, 1990)

Daniel Welch (1980) indicates the role of cognitive conflict in the classroom,

> This paradox is just the sort of thing that creative students produce as they try to understand the connections between things they learn in an elementary course. It is valuable because the contradiction, the crisis, stimulates deeper discoveries. Such paradoxes arise from the naturally creative acts of looking at things differently, from placing ideas in unusual juxtaposition (p. 631).

Kam-Shing Yip (2003) suggests that paradox strategy has contributed to improvement for clients experiencing personal psychological difficulties and that the history of their use for such purposes in clinical settings is long. Yip writes,

> Paradoxical techniques have been used since the early day of psychotherapy (30). In 1914, Alfred Adler was the first one to use and write about paradoxical strategy. Knight Dunlop in 1928 and Victor Frankl (31) in 1938 adopted this as a core therapeutic skill in psychotherapy. Watzlawick, Beavin, and Jackson (32) formalized paradoxical therapy in Pragmatics of Human Communication, later; paradoxical techniques have been widely used in family therapy, couple therapy, and many other psychotherapies.

Psychologists, Marcel Fredericks and Steven I. Miller (1990), point to the reason why paradox provides a tool for psychotherapists, “A paradox is a form of linguistic expression which presents an apparent contradiction but which, when analysed more fully, leads to a deeper insight into a process, a state of affairs, or a phenomenon" (p. 348).

Studying paradoxes provides cognitive conflict for students and their teachers. We feel as if we have a very large and tangled ball of twine. It is enormously frustrating. The ball of twine, even so, has one free end and in my experience if I tug hard enough and for long enough it will eventually unravel. Either that, or, also in my experience, tighten into an irretrievable Gordian knot.

Soren Kierkegaard is quoted in Lewis and Dehler (2000) as saying, "...the paradox is the source of the thinker's passion, and the thinker without a paradox is like a lover without a feeling, a paltry mediocrity." (Cited in M. W. Lewis & Dehler, 2000, p. 708)

My Stipulated Definition of Paradox

Mackie (1973) calls the stipulated definition, "the best of two verbal definitions." The stipulated definition of paradox I use in this thesis is, an unacceptable conclusion derived by acceptable reasoning from acceptable premises. This definition is essentially a reformulation of Sainsbury's (1995 preface) definition, with the adjective 'apparently' excised.

Conclusion

J.L. Mackie (1973) warns me,

> It is sometimes supposed that a definition is a tautology. But this is clearly wrong. Several kinds of statements are called definitions, but even the two which qualify best for being called verbal definitions are far from tautologous. One of these is the lexical definition, which reports how a word is in fact used, in particular what sense or senses it has now or has had at various times; this is clearly informative about the language, it is or should be based on empirical research, and is in fact quite likely to be wrong [author's emphasis]: the dictionary may well tell us that a word was not used with a certain sense before 1850 when in fact it was so used a century earlier (pp. 3-4).

The reader must decide which account of the definition of paradox they will adopt as their own. It is plausible the lexical definition I have just portrayed is false but my stipulated definition must be true.

In 1969 Thomas Kuhn wrote,

> I currently suspect that all revolutions involve, among other things, the abandonment of generalizations the force of which had previously been in some part that of tautologies. Did Einstein show that simultaneity was relative or did he alter the notion of simultaneity itself? Were those who heard paradox in the phrase 'relativity of simultaneity' simply wrong? (T. S. Kuhn, 1996, pp. 183-184)

I am predisposed to suspect that Kuhn was inclined to think that the tautologies, statements true by necessity or by means of their logical form, are unavoidable.

Chapter 5 – The Barber Paradox

> Like the ravens that remind me of my need to contemplate the Paradoxes of Confirmation and Induction, the hair growing on my face nagged me to contemplate the barber who lives in a village, who shaves all men who do not shave themselves. Who shaves the Barber?

Bertrand Russell suggested this self-referential puzzle to illustrate the need to review the system of mathematical logic devised by Gottlob Frege. Russell's Barber Paradox was, and clearly is, more easily comprehended by *paradox novices* such as myself and my students. As for 'The set of all sets not members of themselves' implicated by Russell's Set Paradox, this paradox presents as a mental tongue-twister to all but the most adroit. I never really presented Russell's Set Paradox to my students other than the occasional tentative exploration with small numbers of gifted students, but I felt the need to honour the advice of Mark Colyvan and spend some time contemplating Russell's Set and The Barber. My students were under no such obligation and told me that Russell's Set would not engage them.

Russell's Set Paradox

In May 2011, Russell's Set Paradox turned 110 years old, and is still widely regarded as an indicator of the earth-shuddering capacity of paradox in fields of science, logic, philosophy and mathematics (Cf. Sainsbury, 1995; Chaitin 2002; Scheffler, 1963; Brown, 1911, Richards, 1967; Kleiner and Movshovitz-Hadar, 1994). Russell's Set was nevertheless a baby by comparison to Epimenides' Paradox, which is also known as, The Paradox of the Liar. (Cf. Langford, 1947; Ushenko, 1937; Koyre, 1946; Prior, 1958, Rescher, 2001) Epimenides' Paradox appears in the Epistles to Saint Paul in the King James Bible (Titus: I 12-13) but is directly referenced by earlier scholars such as Diogenes Laertius and Aristotle (Rescher, 2001).

The way that, the somewhat modern, Russell's Set Paradox is often articulated made it difficult for me to comprehend but nonsense to my student population. There is no question attached to the statement; one is simply asked to *contemplate* — 'The set of all those sets not members of themselves'. This set would be both a member and not a member of itself.

An example of a set which *is* a member of itself would be, 'The set of everything which is not a cow'. This set is not a cow and therefore the set *is* a member of itself. An example of a set which *is not* a member of itself would be, 'The set of all cows'. This set *is not* a cow and therefore cannot be a member of itself. It was this second kind of set that Russell asked me to consider.

The Barber Paradox, unlike Russell's Set , seemed more straight forward for my students to grasp very immediately because of the attachment of the question, 'Who shaves the barber?'

The barber shaves those men who do not shave themselves, therefore he can't shave himself and if he doesn't shave himself he must shave himself.

In my quest for greater understanding of the paradoxes of Russell I happened upon the work of Graham Priest, a philosopher now at Melbourne University who courageously set out to resolve the Paradox of the Liar in his book *In Contradiction.* Priest notes that, Russell's Set Paradox was resolved by Ernst Zermelo when he adopted a new set of axioms, which were later to become ZF (Zermelo-Fraenkel) Set Theory. Abraham Fraenkel and Zermelo had altered Zermelo's original axioms, to invalidate the Set Paradox. (Priest, 1995, p.247) Modification of the axioms is reminiscent of the way I dealt with Olbers' Paradox, when I modified the 'premises' or 'assumptions' on which it was based. I have found that these terms are accepted as synonyms by those persons trained in logic but tend to diverge in the vernacular sense because it is usual that the word assumption takes on a negative connotation. 'Assumption' may be seen as something that has been shown to be false. This rendering can create confusion if it is not shown explicitly to be not so.

I became increasingly interested in Russell's Set Paradox because it had seemed to me that after Russell had pointed out the contradictions embedded in

Frege's logic, Russell 'moved the goal-posts' and his logic for dealing with anomalous data was reminiscent of the way in which scientific theories are modified, as in the example of Olbers' Paradox mentioned above. Russell spent a lifetime, a 98 year long lifetime, challenging the assumptions of philosophers, scientists, mathematicians and politicians. Russell was awarded the Nobel Prize for literature in 1950, imprisoned for publishing suffragist propaganda during the First World War and again in 1961 for his anti-nuclear protest. City College denied him employment at the New York campus on the grounds that he was morally unsuitable, because he published "libidinous, lustful, lecherous and untruthful" material. I am unsure which of his many qualities is more admirable but his three volume set, *Principia Mathematica,* written in collaboration with Alfred Whitehead, in colossal bursts of energy—eight to ten hour days, eight months of the year for three years—is indicative of the tenacity, persistence and stubbornness of the man. My journal notes indicate my tremendous struggle with Russell's Set Paradox. I needed to find a little tenacity of my own.

> *Zermelo-Fraenkel (ZF) set theory suggests we cannot assume the existence of the set of all sets that are not members of themselves.*

I engaged with Graham Priest's (1998) 'dialetheism', finding myself exploring the claims that *one* statement could be true and not true, a notion rejected by Classical or Aristotelian Logic, something I call A-logic. In a footnote, in his book *In Contradiction* (2006, p.4) Graham Priest says this of dialetheism,

> The word 'dialetheia' owes its coinage to Richard Routley and myself. Although it is not a *bona fide* Greek word, its Greek roots are meant to be indicative of the Janus-headed nature of a true contradiction…

I used the example below, a transcript from my journal, to test the layman's logic of Priest concept of a true contradiction, cognisant that the Law of contradiction—where A and ¬A (the opposite of A) cannot be both true—forbids my claim.

A Policeman who is both a policeman and a member of the public can be/do things as a member of one set and not do them as a member of another. He has two lives. May an idea have two lives? Therefore what seems to be illegal and legal would depend on context.

Is the liar both a liar and a truth-sayer?

All Cretans are liars – SOLUTION not all just this one.

The 'All' is problematic. Is it not the universal set?

Do most paradoxes stem from universal set theory?

Does the word 'all' mean universal set? Does it therefore make it possible to reject 'All' or 'Either' statements?

I shave ALL those men who do not shave themselves.

The barber is (1) a barber (2) a member of the town.

My confusion over the universal set lasted some time and to the layman, I counted myself as one, the policeman could conceivably be both a member of the public, entailing certain responsibilities and capacities and a member of the constabulary, again, entailing certain responsibilities and capacities. It is conceivable that, in certain circumstances, the responsibilities and capacities would conflict. My solution to my policeman's paradox validated Priest's suggested resolution of the Liar Paradox even in its strengthened form. The Strengthened Liar Paradox was developed to confound the simple solution to the Cretan Liar Paradox I have indicated in the journal note above. During my youth I recall giving this same resolution to a pastor who presented the Liar Paradox to me as some kind of insurmountable challenge.

Might I, like Priest, choose to accept the contradiction, entailing rejection of the Law of contradiction? I can state the Strengthened Liar Paradox differently, minimised to three simple words, 'I am lying'.

Mark (Colyvan, 2001) had reminded me that the choice to reject Russell's Set Paradox was not an easy one.

> The existence of the Russell set is entailed by the intuitively plausible (Unrestricted) Comprehension Axiom. That seems pretty compelling to me.

Mark explained that, like the acceptance of the paradoxical nature of The Paradox of the Ravens, Russell's Set Paradox was based on the acceptance of two, *intuitively plausible* principles. Russell's Set Paradox was based on a plausible Principle that is so basic that anyone could grasp its meaning and that accepting this Principle of Comprehension led to the paradox described by Russell.

The Principle of Comprehension

The Principle of Comprehension (Frege's unrestricted form) reads that for every *statable condition*, such as blackness, there is a class or set of objects, such as ravens, that satisfy the class. Non-self membership is a *statable condition* that leads to the aforementioned contradiction. In the *restricted form* the Comprehension Axiom reads, for every condition there is a class, the members of which *are* the objects that fulfil that condition. This weaker form of the Comprehension Axiom prevents the emergence of Russell's Set Paradox. The abandonment of the intuitively plausible, Unrestricted Comprehension Axiom is responsible for the acknowledgement of the pyroclastic power of Russell's cataclysmic Set Paradox.

I still felt obstinate. Maintaining my view that I didn't have to accept the existence of the set of all sets not members of themselves.

> The Dialetheism of Russell's Set Paradox requires the initial acceptance of the possible existence of the set of all sets that are not members of themselves. Without acceptance and I can't see why this should be assumed, the paradox evaporates.

I was neglecting the fact that the Unrestricted Comprehension Axiom, which I intuitively understood, implied the existence of the 'Set of all sets' and I hadn't at that stage made the bold step to reject that Principle as a means to deny the existence of Russell's Set. Still in the early stages of my exposure to the Barber Paradox I was willing to accept the existence of the 'Barber who shaves all men who do not shave themselves' because the barber was somehow a *tangible* phantom, and unable to accept the *illusory* concreteness of Russell's Set. I asked Mark questions so that I might comprehend the difference between Russell's Set Paradox and The Barber Paradox.

Mark Colyvan explained carefully the standard view of the Barber Paradox, an explanation that was in *total* accord with that expressed by Mark Sainsbury (1995) in his book *Paradoxes*.

> Because there is absolutely no reason to suppose that there is such a barber (and the paradox is only generated on the assumption that there is)

> I don't see what's ambiguous about it. What is ambiguous about someone who both does and does not shave themselves? Moreover, I find the conclusion unacceptable. The problem though is clear to all: there is no such barber!

The existence of Russell's set is entailed by the intuitively plausible Unrestricted Comprehension Axiom and the barber is not necessitated by anything other than the utterers own unwarranted existence claim. However, that did not stop my attempt to resolve the existence of such a phantom.

The Barber Paradox

According to Willard Van Orman Quine (1966) fallacious paradoxes, although Quine calls them falsidical, because he suggests that fallacies can lead to true conclusions as well as false, are so defined because not only is the proposition on which the conclusion is based false, but the conclusion is also false. Quine himself called the Barber Paradox *veridical* because he saw the proposition on which the logic was based was that no town contains such a barber, hence, his label of the Barber Paradox as a veridical or *truth-telling* paradox.

Quine labelled the cataclysmic paradoxes, paradoxes like the Strengthened Liar and Russell's Set, *antinomies*. He reserved antinomies for those paradoxes he viewed had brought about, crises in thought. It was Quine that lead me to Grelling's Paradox (Cf. Grelling, 1936; Herzberger, 1970; Quine, 1966). Quine claimed that Kurt Grelling's Paradox, based upon the adjective, *heterological* also qualifies to be called antinomy. I used Grelling's Paradox to stimulate discussion about paradoxes but I found that because it is principally a discussion about the meaning of words my students would soon fatigue early and I lost traction in discussions with my students.

I decided to read more of Quine's works notably, *The Ways of Paradox* and *Pursuit of Truth.* Quine's naturalised philosophy—studying the actual formation of knowledge without the belief that it was truth—was very appealing. The *Oxford Dictionary of Philosophy* traces the roots of *naturalised philosophy* back to Aristotle and later to Hume and J.S. Mill. Quine's naturalised epistemology appealed to the logical positivist that was lying dormant within this science graduate. I am reminded of the view expressed once by William James,

A new opinion counts as, 'true' just in proportion as it gratifies the individual's desire to assimilate the novel in his experience to his beliefs in stock.

I can attribute Quine's appeal to me to his recognition, which was the same as my own, of the similarity between the advancement in science and advancement in logic. The repudiation of our conceptual heritage referred to by Quine (1966), brought about by Kant's antinomies, was linked to both the Copernican revolution, where the model of the universe according to Copernicus replaced the model of Ptolemy, and where Einstein's 'relativistic mechanics' replaced the heritage left to us by Isaac Newton. Quine informed me there was a time when the doctrine that the earth revolves around the sun was called the Copernican Paradox. And what is truly telling is that even those people who accepted the new model referred to it as a paradox.

I felt that I was transforming my understanding of the advancement of science whilst contemplating the paradoxes of logic.

Science did not chip away at uncovering the *truth*—exposing this *truth* piecemeal. I had come to believe that science advanced when paradox, anomaly, or strangeness, was incorporated by changing the conceptual frameworks upon which the knowledge was hung. In science, *if* we see evidence as anomalous, implausible or false within the existing framework *then* we either modify the conceptual framework or reject the evidence. Changing conceptual frameworks, something that would be required in order to reject the Law of contradiction in the case of the Liar Paradox or the Unrestricted Comprehension Axiom in the case of Russell's Set or the Principle of Equivalence in Hempel's Paradox is never easy and this lack of ease with which change is allowed to proceed is more evident within the field of logic than it is within the field of science. Thomas Kuhn's book *The Structure of Scientific Revolution*s (1996) cites many examples of conceptual change within the field of science that testify to science's naturalised epistemology that avoids focussing on truth but exposes science's inherent truthfulness.

It is unlikely the foundations of logic, conceptual frameworks such as the Law of contradiction, will be discarded or modified without a fight.

I represented to Mark in another email that, IF I had been led by the acceptance of the hypothesis of the existence of a particular barber, and through sound logical processes deduced the unacceptable conclusion of a barber who both does and does not shave himself, THEN by the use of *reductio ad absurdum* argument, the hypothesis on which the conclusion is based must be false and can be rejected, something Mark had already told me.

I then represented the same form of *reductio ad absurdum* argument to Mark to resolve Russell's Set Paradox. Naïvely because the existence of Russell's Set was entailed by our general acceptance of a pretty strong principle, the Unrestricted Comprehension Axiom, and didn't need to be *assumed*, it was known *a priori*, unlike the barber whose existence was not entailed in a similar way. Something I would eventually recognise.

I then tried to use Olbers' Paradox (Britannica, 1994) and the Einstein-Podolsky-Rosen (EPR) Paradox (Savage, 2001) to attempt to persuade

Professor Colyvan that paradoxes were evidence, or the catalyst, for a conceptual framework change.

> If I use the example of EPR to once again draw the discussion back to the point I attempt to make. That being: paradoxes are evidence of anomalies within a theory and the need for a paradigm shift.
>
> You said in reference to EPR, "The response to the EPR Paradox is to accept the intuitively unacceptable conclusion of non-locality." What I suggest is that the conclusion, seemingly being intuitively unacceptable, may in fact be suggestive of an anomaly in the theory.
>
> The paradox arose because of the inability to explain what was after all, a thought experiment, and not a real experiment with genuine data. Bell's theorem, using statistically unacceptable data supposedly supports the view that non-locality is in fact a reasonable conclusion. If non-locality is rejected because it is statistically invalid then an alternative explanation must be found.
>
> What if Heisenberg got it wrong and we can only be uncertain about continuous data, such as momentum and we can be absolutely certain about quantised data, such as spin. Before we measure particle A it can, with certainty have one of two spins along a certain reference frame. The probability is a 50/50 scenario. However the actual spin of particle B is determined during the interaction (A/B), hence no superluminal information.
>
> I have changed my view that, 'all paradoxes are sophistic', because this is suggestive that the paradoxes are deliberately misleading. This I don't think. I do now believe that all paradoxes are evidence of tension between two alternative paradigms (T. S. Kuhn, 1962).

Mark (Colyvan, 2001) thought that my strengthened interpretation was, "…far too strong now." He preferred to represent what paradoxes signify as follow.

> A paradox demonstrates that two bodies of knowledge are inconsistent – it might be resolved by revising as little as one proposition. It does not necessarily involve anything so radical as a "paradigm shift". (Indeed, I'm somewhat sceptical that there are any genuine paradigm shifts.

The challenge represented by Mark's remarks contradicted what I knew of science. I disliked his rejection of the 'paradigm shift' concept as too strong, because of my acceptance of the principles of logic that I saw driving the progress of science. I would think that the rejection of the Law of contradiction, proposed by Graham Priest's dialetheism, would certainly qualify as a paradigm shift and as Mark had already expressed favouring dialetheism for resolving the Liar Paradox he seemed to be contradicting a position he had held earlier.

> Do you assert that there has never been any paradigm (assumption/axiom) shifting? You said the Russell Set Paradox stimulated the process of change in set theory. Do you see this as an expansion of the pre-RS Set Theory or was the set of assumptions re – set theory significantly altered? Do you view this change process as a kind of evolution?
>
> Olbers' paradox dramatically changed the view of the universe from the infinite static U. Does this not constitute a paradigm shift?
>
> The naïve view of evolution is a gradual, geologically slow process. SJ Gould and others suggest long periods of stability followed by brief periods of rapid change, which is strongly suggestive of paradigm shifting even within the evolutionary context.

When Mark replied he softened his attack.

> Theory change and paradigm shifts are two radically different things. Of course there have been changes in theory but genuine paradigm shifts are harder to come by. I'm basically complaining that the phrase 'paradigm shift' is overused --- it is often used nowadays to mean little more than a new way of thinking about an area. You should look at Kuhn to see what a genuine paradigm shift involves.

My copy of *The Structure of Scientific Revolutions* (1996) arrived, courtesy of Amazon. Kuhn's book was destined to make a strong impact because his ideas were in strong accord with those ideas I already held. Kuhn showed the link I was searching for between Karl Popper's Falsification Principle (1972), and my study of paradoxes guided by Quine's naturalised epistemology. Kuhn and Matthews (2004), write about Popper's rejection of verification in favour of falsification by associating it with his view concerning the role of anomalous experiences, experiences that, by evoking crisis, prepare the way for a new theory. Kuhn did point out that although Popper saw the use of falsification would overcome the inherent probabilistic nature of verification, Popper may have simply swapped the difficulties faced by verification, as demonstrated by Hempel's Ravens, for the, 'equally' probabilistic nature of falsification.

> Olbers' paradox was fairly bloodless, I suppose, and really it represents one piece of evidence leading from the Infinite Static Universe (I.S.U.) to the Inflationary Universe model. But the whole process may have pivoted on this paradox. I'm suggesting it is analogous to a keystone. The change from the I.S.U. has not been finalised and I would suggest that the scientific revolution is still under way.
>
> Are the change agents in genuine paradigm shifts paradoxes?
>
> Do you view the scientific notion of 'anomaly' synonymous with paradox? I believe at one time the orbit of Mercury was seen as a paradox and not an anomaly.

Mark disagreed with my 'change agent' view of the nature of paradoxes. However, he indicated (below) that for him this was driven by his own conceptual understanding, from the fields of mathematics and philosophy, of what a paradox was. He recognised that given my own, differing, understanding of paradox, and I hadn't yet decided how it was different, it was conceivable that people with similar views about the nature of paradox to me would concur.

> I wouldn't think that they would necessarily have to be paradoxes (though, of course, this depends on what you think a paradox is --- evidence that disagrees with theory doesn't seem like a paradox to me and many alleged paradigm shifts were (arguably) driven by recalcitrant experimental evidence.
>
> Personally, I'd not be inclined to call the advance of the perihelion of Mercury combined with Newtonian mechanics (or even with special relativity) 'a paradox' (though I can see why someone might wish to).

Exploring the Barber Paradox in my journal I found myself logically revealing its paradoxical conclusion.

> *Does the barber wear a beard? What possibilities exist to allow the barber who shaves everyone who does not shave themselves? If*

he did wear a beard, he would not shave himself and therefore the barber must shave himself – paradox. Does the barber shave himself? If he does then he disqualifies himself from being shaved by himself – paradox. Does the barber have somebody else shave him? If he does then he does not shave himself and so must shave himself – paradox.

To qualify for being a paradox The Barber Paradox must be based upon an: apparently acceptable premise, sound reasoning or an unacceptable conclusion.

I shave all those who don't shave themselves. This statement can be: true, false, neither true nor false, both true and false (if Dialetheism is accepted), none of the above or all of the above.

Dialetheism! The ambiguity of the paradoxes may be true in one respect and false in another. This example of the Barber Paradox is therefore contradictory. Paradoxes of self-reference e.g. Liar and Russell's Set, if the logic is true, support Dialetheism. Rationality appears to hinge on the acceptance of the Law of contradiction (often referred to as the Law of Non-contradiction). The rejection of scientific theory is based upon: undue complexity, the theory is considered contrived, there exists unobserved consequences (Olbers's lit night).

Phlogiston Theory Part 1

Phlogiston Theory was for me a good illustration of how a scientific theory is rejected with which I thought I may engage Mark with my paradigm idea.

Until Antoine-Laurent Lavoisier developed a greater understanding of oxygen and oxidation, Phlogiston was blight on the good name of science because of the insistence of a few respected scientists *dogmatically clinging* to a theory that shown to be unsound. Phlogiston Theory (T. S. Kuhn, 1962; University, 1997) was very much supported by people such as, the respected, Joseph Priestley. It is said that Priestley would not recant even on his death-bed, and if that is so would give credence to my view that Priestley was not a scientist at all, merely a gentleman with time on his hands and the financial resources to support his pseudo-scientific inquiries. Although Mark rejected Phlogiston Theory's status as a true example of a paradigm shift, I could see that a combination of paradox and anomalous data brought about the final rejection of Phlogiston Theory. I wrote to Mark,

> Phlogiston is an interesting example of science gone completely wrong. The need to resort to unreasonable conclusions (negative mass) in order to continue to support the old order. Is this why you would believe it may be an example of a paradigm shift?

The intuitively implausible consequence of Phlogiston should have been enough for any person guided by logical principles to reject Phlogiston Theory, but not for Priestley. The similarity between the action of Priestley and the action of adolescent scientists as demonstrated by a young person's failure to relinquish illogical beliefs was deserving of further exploration. I had seen countless examples of students hanging on to their view in the face of overwhelming evidence. The Mpemba Effect was one such example. Students with no evidence at all still thought the Mpemba Effect was real, and yes, it is real but the point is the students initially had no evidence that it was real. They had duped themselves by second guessing me.

Mark conceded that he was not sure that Phlogiston was an example of paradigm shift.

> I'm not convinced that it was a paradigm shift.
>
> The alternative is that change as indicated by revised, reviewed and changed theory is a continuum and there is no obvious line that indicates the difference between theory change and paradigm shift.

Mark suggested that many alleged paradigm shifts were, arguably, driven instead by recalcitrant or unmanageable experimental evidence.

> Think of the move to relativity theory (which is alleged to be a paradigm shift). This move was motivated by a few pieces of data that were proving problematic for

> Newtonian mechanics (namely the Michelson-Morley experiment, the advance of the perihelion of Mercury and a few other bits and pieces). This recalcitrant data provided the motivation for the new theory (though it's not clear how prominent a place this data had in Einstein's thinking at the time of the special theory at least).

I understood his point regarding recalcitrant data and accepted that in the case of Phlogiston Theory the rejection took a little longer than usual because of the complete absence of an alternative theory to explain observations, something that is mentioned by Brewer and Chinn (1994) and previously in their joint paper, *The Role of Anomalous Data in Knowledge Acquisition: A Theoretical Framework and Implications for Science Instruction* (Chinn and Brewer, 1993).

> What you describe here is an anomaly (recalcitrant data), an observation that is not in agreement with your existing theory. In your example, Michelson and Morley's did not expect an answer of 0m/s in their 1887 experiment. The Lorentz contraction was proposed to explain away the anomaly. Is this good science? I would propose that basing an hypothesis on a scaffold containing no evidence is fraught with danger. Kuhn says that at first the scientist attempts to explain away the anomalous result by suggesting it may be due to inadequacies in the measurement of the data (sometimes this is true!), but this is not the case in the M&M exp, which should have been able to measure the velocity of the earth through the ether.
>
> If the anomalous evidence persists it would provide stimulus for theory change. Lavoisier's mass evidence in the case of Phlogiston Theory provided the stimulus for dumping P.T. and replacing it with oxidation. Adaptation or new theory? Maybe this is a case of radical change and therefore paradigm shifting. Using the Lorentz transformations to explain the anomalous results of Michelson and Morley seems to be only an adaptation of the existing theory.
>
> What we both agree upon is the belief that theories, in nearly all cases are only adapted and not thrown out.
>
> Lamarck believed in spontaneous generation as did many of his contemporaries. We now, with considerable hindsight, scoff at the very idea that anybody could ever have believed in such a silly theory [Although the Australian Ted Steele is encouraging the theories' revitalisation]. Reproduction is now understood well and maybe this change can be seen as a paradigm shift. In the future will our work be

> scoffed at in a similar way or have we developed sufficient scientific rigor to deny this?

Throughout my dialogue with Professor Colyvan I was influenced by the philosophy of John D. Barrow (1999), and read his book, *Impossibility: The Limits of Science and the Science of Limits* whilst engaged in our correspondence. Barrow's book together with Brian L. Silver's (1998) *Ascent of Science*, Richard P. Feynman's (1998) *Six Not-So-Easy Pieces* and Thomas S. Kuhn's (1962) *The Structure of Scientific Revolutions*, provided a conceptual framework for my view of the progress of science by the 'conjecture and refutation' championed by Popper. All four books confirmed my view regarding the nature of science and the role of evidence, especially anomalous or paradoxical evidence as being a driving force behind theory change. Therefore the books encouraged my persistence with exposing my students to paradoxical or anomalous evidence as a means to encourage the students to change their own theories.

Paradox and Truth

The incongruence between the logician's (Mark's) interpretation of paradox and the scientist's (my own) interpretation were indicative of the breadth of interpretations of the word paradox in common use and this point will be extended further in my next chapter devoted to the development of my own stipulated definition.

John Barrow's book opens with an account of the limits of science being linked with paradox. Bertrand Russell's Set Paradox and the Barber Paradox were used by Barrow to suggest the potential for collapse of the, "…entire edifice of human reasoning…" My strong feeling of kinship with Russell is elucidated by Barrow quoting from Russell's, *The Principles of Mathematics*:

> Every morning I would sit down before a blank sheet of paper. Throughout the day, with a brief interval for lunch, I would stare at the blank sheet. Often when the evening came it was still empty…it seemed quite likely that the whole of the rest of my life might be consumed in looking at the blank sheet of paper. What made it

> more annoying was that the contradictions were trivial, and that my time was spent in considering matters that seemed unworthy of serious attention.

Writing and playing with paradox is to me *all consuming* and yet I found I made slow progress often staring for days at scraps of paper covered with a tangle of labyrinthine statements or blank screens. Humanity has made some progress in the intervening years. The blank screens waiting patiently to be filled with lucid, coherent and confident expositions of the paradoxes, and my view on the role that studying paradoxes could play in developing my students' understanding of scientific evidence.

It was Barrow who showed me the importance of the Polish-born American, logician Alfred Tarski (1956), and in particular, Tarski's notion of truth encapsulated by his book, *Logic, Semantics, Metamathematics*. (Cf. Etchemendy, 1988; Kripke, 1975; Popper, 1955; Tarski, 1956)

Tarski considered a statement true, if and only if it was true. The statement, 'Snow is white' is true if, and only if, snow is white is used by Tarski as an exemplar. Although this formulation was intuitively plausible, even palpable, I couldn't understand why there was such need for this interpretation. Tarski's notion of truth held implications for science and science's truthfulness.

Barrow thought nature's consistency implied there are no *true* paradoxes, at least within the field of science. I thought there was some need to question whether Barrow's assumption of a consistent world was true in the light of Tarski's notion of truth. It appeared that, given inconsistencies were often discovered, perhaps it is Barrow's assumption that ought to be called into question. Barrow (1999) repeated the words of mathematician and physicist Hermann Weyl, "…nowhere do we find any real contradiction to the facts directly presented to us in experience (Barrow, 1999, p.200)." Even Weyl qualified his claim by inserting the adjective 'real'. Something I find very reminiscent of Colyvan's choice of the adjective 'apparently' in his definition of paradox.

The Grandfather Paradox may present as an example of a real contradiction. If I examine the Grandfather Paradox; the possibility to go back in time and kill your own grandfather, it provides a refutation of Weyl's conjecture.

The Grandfather Paradox is disallowed by Stephen J. Hawking's Chronology Protection Conjecture. Hawking's conjecture was the response to the thought experiment that was needed for maintenance of the view that nature and therefore science has the consistency suggested by Wehl. The premises, or assumptions, on which Hawking's conjecture is based, nature's consistency and the genuine possibility of time travel, necessitate the Chronology Protection Conjecture, disallowing the time traveller's intervention in her own future.

In the case of the Grandfather Paradox, the hypothesised paradox is only paradoxical if we first accept the possibility of time travel and the consistency of nature, despite the intuitive implausibility of time travel. Rejection of one or other assumption is one method that Sainsbury (1995) would use to resolve this paradox. But, according to the Australian physicist Paul Davies's (2001) in his book, *How to Build a Time Machine*, time travel is genuinely possible and so to be dismissive of the premise is not straight forward and no sure way to resolve this paradox. I can conclude that Hawking's Chronology Protection Conjecture is not necessary if I reject the possibility of time travel. If time travel is genuinely possible, I either have to reject the consistency of nature or support Hawking's *ad hoc* Chronology Protection Conjecture.

More Thought Experiments

The use of thought experiments to reject implausible conjectures has significance in the science classroom, because thought experiments can streamline the experimental design process; they are an invaluable tool. Ernest Rutherford's suggestion that lack of money must oblige thought can be relocated as—lack of time must oblige thought experiments.

A student, James thought that on a balanced beam if masses are added, one at a time, to one end, the distance these masses were placed from the pivot point must halve each time an equivalent mass is added. With a thought experiment James destroyed that notion by concluding there would come a point where the distance was so small the masses would be resting on the pivot yet more mass could be added. This made no sense to James, "…it contradicted common sense" (James's words). James invested a little more time in discovering the turning effect of a lever was force multiplied by length as a consequence of his own thought experiment.

In my view, paradoxes and thought experiments have a lot in common. Following is an example of my own thought experiment I shared with my students.

The Tasmanian Tiger

Consider the following conjecture regarding Tasmanian tigers (*Thylacinus cynocephalus*), 'Thylacines are extant'.

My students, in response to this statement readily designed an experiment to test this conjecture that involved the setting of remotely triggered surveillance cameras distributed throughout Tasmania. If this strategy fails to capture images of Thylacine then the statement 'Thylacine are extant' fails to gather support. The follow up question I ask my students is can this conjecture truly be tested by this method? I then asked my students to consider the conjecture, 'Thylacines are extinct'.

When a scientific conjecture is tested, pairs of conjectures, this and not that, are tested and therefore it is equally valid, or more appropriate, to examine evidence pertaining to both conjectures. Evidence that would refute 'Thylacines are extinct' would include; carcasses, hairs, scat, sightings and the like. Failure to find carcasses would add significant support to the conjecture, 'Thylacines are extinct'. Yet it is not possible to find proof of the extinction of the Thylacine in the same way it is not possible to prove the non-existence of the mythical unicorn.

After the initial student responses I confessed my own sighting of a Tasmanian tiger:

After a late night studying at the Morris Miller Library at the University of Tasmania, I head home to Ouse District High School where I was accommodated at a school house. The distance from my front door to the door of the main staff room was seven large paces. The time was about 10:00pm so it wasn't really late when I saw the tiger, and I wasn't particularly tired but my students agreed amongst themselves that I must have been exhausted. Now, I can swear with my hand on my heart that I saw a Tasmanian tiger that evening when I was returning home. As I was travelling along a straight section of road between the Hayes Prison Farm turnoff and the town of Hamilton I saw in my headlights what appeared to be a rather lame and aged Labrador dog, and seeing that I had my utility I felt I should put the old dog in the back and find its owner in the morning. As I slowed to a stop the animal turned side-on to my head-lights and the stripes over its rump were fully illuminated. The camera in the centre console of my utility was a dim memory and I regret, to this day, I didn't reach for it and snap away. Perhaps though, my story would have a less interesting conclusion. When I had arrived at my accommodation I was so excited that I had to tell someone, however, I was astute enough to realise that no sane person would believe me and my only recourse was to telephone my wife Sue, for surely, if anybody, she would believe me. She had never laughed so hard! When I hung up the phone I was a little flustered but decided that I could find the exact location in the morning and surely there would be footprints, scat, hair, something. Then, that night, two inches of rain fell and all my hopes washed away along with the trace I never found.

The average person looks for confirmation of conjectures, not refutation. My students would look for confirmation. It would possibly appear from my story that I now claim that Tasmanian tigers are still alive, but this would not be so, in spite of the hand-on-heart claim I support the philosophy of Popper. Failure to confirm conjectures may cause the average person, whom has not seen a tiger, to persist with their conjecture, ‘Thylacines are extant’ because they do not recognise the inability to prove, ‘Thylacines are extinct’.

What we can do is to test the claim properly by attempting to locate evidence that would falsify the claim, and there is plenty of it. For example, it is estimated that some 293 000 native animals are killed annually (http://www.roadkilltas.com/) and it would be reasonable to claim that this number of road kill would be the average over the last 80 odd years, back to the last remaining, captive, Thylacine which died in 1936. Not one of those bloodied and broken carcasses was a Tasmanian tiger. That would be pretty compelling evidence for the refutation of any ‘extant’ claim.

So what do I do with my sighting and many others from credible sources? I look for an alternative, plausible and rational explanation for what I believed I saw. My students could come up with plenty in the space of 20 minutes. Some student alternatives involved the use of illicit drugs but many were very much mainstream and above all, rational possibilities. Wattle tree shadows cast on a Labrador dog being one.

Studying the Paradoxes of Confirmation, such as Nelson Goodman’s, *New Riddle of Induction* (Goodman, 1946), concerning the adjective ‘Grue’ or Carl Hempel’s Paradox of the Ravens might allow students to revise their reliance on confirmation, confirming the superiority of refutation as the means for progress in science. My students, whom I challenged with my story of the Tasmanian tiger, were able to utilise Sainsbury’s paradox resolution strategy to resolve this dilemma of truth and belief.

I rejected Goodman’s Paradox *Grue* because I considered it unnecessarily complex and a little contrived whereas Hempel’s Ravens had a basis in the real world and Grue was imaginary at best. It was clear to me that in order to study paradoxes my students would be required to develop their own conceptual understanding of the word paradox.

Chapter 6 – The Money Spider Hypothesis – a case study

One day some students in my grade 9 Science class found a green spider in our classroom. I lifted the spider gently on to my hand and allowed it to crawl about. Kahli was horrified when I let the spider crawl on my hand; other students were not horrified although they were reluctant to do the same. I referred to the little green spider as a, ‘money spider’ in the hope that I would stimulate cognitive conflict about the plausibility of such a superstitious notion. I also hoped that Kahli or another student would overcome their irrational fear and allow the spider to crawl on their skin. I told my Grade 9 Science students that some people believe that allowing a spider such as this onto their hand would bring good fortune. I said, rather ‘tongue in cheek’, that money was coming my way soon.

The relics of superstition fester like the skin lesions named necrotising arachnidism. Until 2003, the blame for this horrifying condition lay with the white-tailed spider, *Lampona cylindrata*.

The Gullibility Gene

Reading Richard Dawkins’s (2006) book, *The God Delusion*, I was struck by the idea that a person’s propensity to think rationally might be genetically predetermined in the same way that one would inherit Huntington’s chorea or tongue-rolling. What could be the implications for science education if many people are genetically compelled to believe extremely speculative and implausible hypotheses?

Assuming genetic regulation of an individual’s propensity to believe supernatural explanations and superstitions, and acceptance of authoritative decrees that are logically flawed, the survival of this human trait must have its origin in natural selection and the selective advantage faith or ‘blind’ acceptance offers. Dawkins suggested that the religious beliefs, professed by so many, could be the result of a by-product of a need for very young children to accept “mindlessly” the demands of their parents to avoid being snapped up by, amongst other things, hungry crocodiles.

Dawkins sees no obvious and direct selective advantage for this behaviour and refers to it merely as a “by-product”. I think the number of individuals that accept superstition is suggestive of a more direct genetic route. The way that Dawkins illustrates rationality makes it clear that he polarises rational and irrational thought. Dawkins demonises irrationality. I no longer support this polemic although at one time I am sure I did share Dawkins’s view. I believe the polemic Dawkins establishes to be both dangerous and unnecessary because driving a wedge between the two types of logic users prevents the benefits evolution has derived from their inclusion.

Although I once spurned irrationality, my studies have encouraged me to embrace the possibilities that emerge from the collapse of Dawkins’s polemic. Could it be that holding rational thought in abeyance, rather than being irrational and harmful, was advantageous to primitive man. The selective advantage of avoidance of rational actions and thought may offer a selective advantage. I originally saw irrational ideas to be wholly negative and rational ideas to be wholly positive. I failed to recognise the potential for the opposite to be also possible.

To examine the pervasiveness of the avoidance of rational thought and an example of an experience that helped to transform my own understanding I will retell the story of the money spider.

The Money Spider

In the afternoon of the same day the money spider made its appearance, I telephoned my computer repair man to ask if he could repair my computer after a surge in the local power supply fried my computer’s internal power supply. The first couple of attempts to contact the repairman resulted in the reception of a computer-simulated voice suggesting I had dialled the wrong number. I rechecked the number–it was correct–so I tried again. Again I heard the computer-simulated voice. I rang directory inquiries and asked for the correct telephone number. The operator gave me the same number I had just been dialling. When I tried telephoning for the third time I got through, again to a computer-simulated voice, but this time it was an answering machine. I was a bit furious because it was the same number I had to dial directory assistance for and the telephone company would charge unreasonably for the inquiry. My frustration led me to telephone the faults reporting number.

The person I reached checked the number I was calling and said that, "it would appear there is nothing wrong at their end." I suggested I should not have to pay for a directory assistance call that I didn't genuinely require, as I had only telephoned assistance after there *was* a fault on the line, albeit one that couldn't be detected later. This person could not reimburse me but suggested the telephone company's accounts department could assist in my request. The kindly person put me through to 'new connections' instead of 'accounts'. Another kind person connected me through to 'accounts' and yet another agreed to reimburse my $2.50 and offered a further $150.00 for, as he put it, "a good-will gesture" and then on top of that my power company agreed to pay for my damaged computer.

Frankly, I was stunned; my money spider was omnipotent. Any instance of a generalisation constitutes evidence in support of the hypothesis. This small green spider potentially explained my good fortune. When I reported this good fortune to my Grade 9 Science class at the next opportunity, Kahli said that she thought that the spider *did* explain my good fortune. I am not sure that she was joking.

Theory Confirmation

Kahli's mode of theory confirmation, dependent only upon covariation, appears to be common amongst the children I teach and many adults I know. It appears that there is little one can do to arrest the prevalence of the false logic. Covariation alone is not enough to justify causation, not in the case of my money spider and not in any other case. Just because every person buried in my local cemetery has eaten carrots does not mean the carrots they ate caused their demise. Even with extraordinary levels of education there would appear to be a tendency, in unguarded situations, to accept covariation as confirmation. The work of Koslowski (1996), mentioned previously, reinforces the view that non-causal beliefs are immutable.

> …anomalous evidence that includes an explanatory mechanism has a greater effect on causal than non-causal beliefs, that is, on precisely the sorts of beliefs that Deanna Kuhn (1989) and others found to be the more resistant to change. (Cf. Koslowski, 1996, p. 257; D. Kuhn, 1989, 2005)

The desire to believe on the basis of a single piece of covariation, the thesis that the money spider had contributed to my good fortune in the form of a $150.00 windfall and the repaired power supply, overlooks other equally important aspects of causation, particularly that there needs to be a plausible explanation of the causal mechanism linking, the money spider with the good fortune I had received.

Why do many individuals believe that such a thing is plausible? Might these individuals, holding only Hume's three elements of causation: correlation of events, priority and contiguity, believe they are justified in their conclusion? A spider crawled on my hand followed by a windfall and some students believed there was a connection (contiguity). It appears that contiguity is the weakness. The fourth causal element, added by D. Kuhn (1989, 2005) and Koslowski (1989, 1996), is absent, the coordination of an explanatory mechanism with evidence. Supporters of the money spider hypothesis have erred. Kuhn would say, "…these skills in coordinating theories and evidence arguably are the most central, essential, and general skills that define scientific thinking. (Kuhn, 1989)"

The response given by supporters to evidence that refutes the money spider non-causal hypothesis would include, 'it didn't work this time but that even science is inconsistent.' Some people are convinced of the money spider's ability to bring good fortune, others merely delight in the coincidence. Incidences of correlation do not convince me of causal agency due to the lack of a plausible explanatory mechanism.

Irrational Belief

To illustrate consequences for people who ignore the role of an explanatory mechanism in causation I report the following case. Many years ago I worked with a man who regularly went to see an alternative therapist to have ‘negative energy drained away from his body’, enduring ‘cupping’. Cupping is a ‘treatment’ whereby a therapist places heated glass bowls on a patient’s back, the cooling of the gas inside the vessel causes the gas contained to shrink and the skin makes a serious attempt to climb into the bowl. The resultant bruises on my colleague’s back gave it the appearance cricket balls struck him repeatedly. I was appalled to see abuse masquerading as therapy. Besides suffering this abuse my colleague had paid for this treatment. Why do people choose to suffer what I believe to be such indignity? Hindus believe that the cleanliness of the messenger sent to fetch the doctor to administer the cupping has an effect on the outcome. Was my colleague an irrational believer?

If some of the students I teach fall into the category of irrational believers, people who believe on apocryphal or mythical grounds, it might well be important to cater for such students in my classroom, perhaps proselytising the virtue and concepts of science rather than attempting any rationally developed understanding. As a teacher of science, I attempt to change my students’ false understandings into accepted scientific explanations of phenomena. I’d rather do this by exposing students to the possibility of transforming their own understanding but this approach may not be possible for non-causal believers.

Until I was able to acknowledge the significance of students’ unwarranted or unjustified knowledge claims I would have considered challenging their unjustified beliefs by asking them to correlate their own theoretical understandings with available evidence. Then, I would offer evidence that would appear to the students to contradict their positions—specifically in the form of a paradox, hoping to generate cognitive conflict. Providing students with sufficient conceptual conflict I believe would result in the necessary change that I require of them, in that they would swap their existing unwarranted naïve conceptions for those more properly justified scientifically.

That would only be so if the students in question were rational thinkers. Many students fail to change their understanding. I wondered whether some students were genetically determined irrational thinkers as opposed to culturally determined irrational thinkers and whether this could be a reason for them being unable to exchange their unwarranted claims for claims more scientifically justifiable.

Paula Findlen (1990) interestingly does not consider the dichotomy in 'black and white' terms and, instead shades the meanings of the terms 'rational' and 'irrational' to reflect their usage during the 16^{th} and 17^{th} centuries. Findlen points to the 'greying' in the *comic encomia,* theatrical performances utilising the comic nature of absurdities. As a literary device the comic encomium is equivalent to 'paradoxes' of nature, like rocks (fossils) that looked like animals and plants, which captivated the Renaissance naturalist.

Perhaps some students are genetically hard-wired to avoid rational argument. If this were true, the stratagem used by religious organisations, parents or perhaps the mythic practice of Egan (1997) might be justified to engage with those students genetically predisposed to irrational ways of thinking. Although Egan encourages mythic practice he also encourages science teaching to be rational when he says,

> What is attainable, though, is the sceptical, philosophical, informed mind that energetically inquires into the nature and meaning of things, that is unsatisfied by conventional answers, that repudiates belief in whatever cannot be adequately supported by good arguments or evidence, and that embodies the good-humored corrosive of Socratic irony (p. 18).

Schools are conflicted places, in part, because they contain variant 'types' of logic users. Extreme rationalists have a 'devil of a time' comprehending people that behave irrationally. Unguarded, I dismiss irrational individuals' beliefs. I suspect that these same people would likewise have a 'uneasy time' comprehending people like me and may be equally dismissive. Like the insularia, the part black and part white Peppered Moths of Bernard Kettlewell (Grant, 1999) it is likely that variation exists between the two extremes. A selective advantage may be available to people who use both rational and irrational strategies for understanding.

What then might be some of the advantages and disadvantages of these strategies for understanding? The first Australopithecine to shove his hand into a nest of bees probably would have discovered shortly thereafter that bees can sting. The observant rationalist within the clan would choose never to put their hand in a nest of bees given what he had just witnessed. The irrationalist may give it another go, against the best advice of his cringing rationalist companion, and discovered the honey within, an entirely new source of energy rich food. This discovery might offer their clan a selective advantage over other, less rationally diverse, populations.

Within a population of primates, similarly to the Australopithecines just mentioned, the rationalists amongst them may be seen as timid and the irrationalists considered adventurous. It is possible that a troop of monkeys that contains both types of individual is selectively advantaged because the timid primates help to keep the troop safe from predators and the adventurous primates allow the troop to venture into unfamiliar territory when food is in short supply and there is a need to forage for food away from the safety of their familiar territory. A troop of primates containing only one or other type would be disadvantaged. A troop made entirely of adventurous individuals would carelessly allow predators into their midst whilst a troop made entirely of timid individuals would remain in one location, deprived of food, they would starve to death rather than risk the dangers associated with the unfamiliar.

If Science teachers currently assume students of Science are predisposed toward rational modes of thought, what I could describe as correct epistemic logic, what are the implications for the teaching of science if that assumption, is not true?

As the Mpemba Effect, explored earlier, shows it is often difficult to shift students' existing non-causal misconceptions.

A rationalist who is confined or restrained by his reason and use of evidentiary logic tends to disregard, or worse, disrespect other ways of knowing. After the IQ debate opened up with the publication of *The Bell Curve* (Herrnstein, 1994) it became reasonable for the scientific community to assume the malleability or mutability of intelligence and the same could apply more specifically to reason and consequently argumentation. In spite of the differences between individuals' capacity to use logic I can reasonably assume that any individual's use of logic could improve, given the support by a considerate teacher.

To prolong the discussion with my colleagues and students, I raised this complex issue, again with spiders, when I published an argument in the school newsletter exposing the irrational belief in the deadliness of the bite of the white-tailed spider. Many people in my school community believed irrationally that the white-tailed spider's bite causes, what researchers refer to as, necrotising arachnidism—arachnid induced tissue death. This plausible hypothesis to explain unresolved cases of necrotising lesions became, in the hands of a scientifically illiterate public, scientific truth; truth transferred, somewhat memicly, from citizen to citizen, when the citizen was not of a questioning disposition. In spite of a dearth of evidence linking the white-tailed spider with necrotising lesions, the broader community willingly participated in the deception.

When Geoff Isbister and Mike Gray (Isbister & Gray, 2003) completed their beautiful study, falsifying the myth, the claim was finally laid to rest in the scientific community. Unfortunately, the myth lingers in the wider community. Isbister and Gray's evidence might never fully satisfy some members of our wider community, perhaps because of genetic variations in human rationality.

The lack of credibility and the extreme resilience of claims about the white-tailed spider fascinate me. I think it possible that this situation offers me the opportunity to demonstrate the critical attitude I am encouraging my students to develop.

The story I told my students and the subsequent article in the school newsletter acted as a stimulus for further discussion about the process a scientist would use to test the truthfulness of knowledge claims.

I suspect that the reason for the negative reputation of this common Australian spider was the combination of the flippant nature of the title of Struan Sutherland’s article, *Watch Out, Miss Muffet* (1987) which had stimulated broad readership, and Sutherland’s *unquestionable authority.* Sutherland’s authority blinkered, potentially critical, scientific eyes. This conjecture currently remains untested.

The longevity and prevalence of myths, such as the White-tailed Spider causing necrotising arachnidism, illustrate the power of *authority* and reinforce my idea that due care should be taken by those, like myself, in whom *scientific authority* and rationality is vested.

This case study forces me to remember the value of irrational modes of thought. It is such thoughts that allowed my students to take risks when the evidence might be quite compelling to do the opposite. Like the courageous australopithecine, students take advantage from occasionally ignoring their rational selves to choose instead, like our forebears, those options that ordinarily they might fear to take.

Chapter 7 – Diabolical Internal Dialogues – my fictionalised story

In his book, *For and Against Method*, Matteo Motterlini justifies his use of a fictional dialogue between two real people: Paul Feyerabend and Imre Lakatos. Motterlini's re-creation of a long-term conversation between Feyerabend and Lakatos in no way detracts from what I was able to learn from these two great philosophers.

Motterlini chose Diogenes Laertius, to claim that dialogue trumps essay.

> A dialogue is a discourse consisting of question and answer on some philosophical or political subject, with due regard to the characters of the persons introduced and the choice of diction. The dialectic is the art of discourse by which we either refute or establish some proposition by means of question and answer on the part of the interlocutors. (D.L. in Motterlini, 1999, p.1)

In my fictional stories that follow there exists a dialogue between two characters, and like Motterlini's use of Feyerabend and Lakatos I represent an account of my internal dialogue.

Motterlini allows the two interlocutors, Feyerabend and Lakatos to explain the reason for adopting fictional dialogue. It struck me as a fine justification for using dialogue in addition to essay in this thesis.

> Paul Feyerabend: Rumour has it, dear Imre, that while one can freely discuss ideas in a loose way, in letters, phone calls, and at dinner, academics will always prefer an essay or a book. And any paper of this kind has a beginning, a middle, and an end. There is an exposition, a development, and a result. After that the idea is as clear and well-defined as a dead butterfly in a collector's box.

> Imre Lakatos: Plato thought that the gulf between ideas and life could be bridged by dialogue not by a written dialogue, which he considered but a superficial account of past events, but by a real, spoken exchange between people of different backgrounds. I agree that a dialogue reveals more than an essay. It can show the

> effect of arguments on outsiders. It makes explicit the loose ends which an essay tries to conceal by showing the inconclusiveness of "conclusions"…

Feyerabend and Lakatos show distain for sanitised and homogenised thinking and an awareness of the inconclusiveness of any philosophical dialectic. I believe the 'real' Paul would have delighted in the notion of the inclusion of my irreverent stories with their coarse and common vernacular. No doubt Paul would ask why I felt the need for this form of chaotic argument—perhaps he would even call me an obfuscator.

Originally, I hoped that I could withhold the interpretations of each part and allow my reader to interpret the stories as they saw fit. If I had done so Feyerabend's tag *obfuscator* would belong to me. My story is autobiographical, describing my labyrinthine journey of discovery of the paradoxes that have occupied my life for so long. By composing this dialogue I gave myself some freedom in writing about the paradoxes in a less than scholarly way. Many of the paradoxes I have studied only opened themselves to me after conversations with friends and colleagues when I attempted to articulate and explain to them their significance within science. I struggled to understand each and every paradox I contemplated, even those I managed to resolve to my own satisfaction. I contemplated the paradoxes by carrying out an eternal, never-ending, interminable dialogue, and I found it useful to record the dialogue between my two, not-so-fictional, characters. I imagined conducting the internal dialogue with my, very real, closest friend Charles.

The two characters in my story are Charles and his friend. Both characters represent me. Charles is delusional as his friend is not real. Charles's conversations with his friend show the feelings, thoughts and uncertainties I felt when analysing the paradoxes. The conversations express my internal dialogue. With some reluctance, because of my appalling language, I think it is worth sharing, and yes I really do speak like this when mother is out. Charles is delusional, he has conjured his friend. Together we examine the potential for the study of paradox to link evidence, logic and theoretical knowledge within the field of science.

The dialectic Charles conducts attempts to expose the propositions that are central to this thesis: the truthfulness of science, the illusive nature of identity, the nonsense of common sense, and the uncertain nature of linguistic meaning without restraint from the principles of logic.

There are six chapters to my story. The first describes something that is common to all humanity, a strong inclination to believe in inductive proofs and thereby generalisations such as — metals expand when heated, and thereby universal laws such as — all bodies attract all other bodies according to the inverse square law.

But there is something very wrong with universal laws. Stephen Toulmin (S. Toulmin, 2001, p. 111) reminds me that,

> A universal was for the Greeks a *kat'holou*: this meant just the same as the English phrase "on the whole" — in the sense of "generally" — as it still does on the streets of Athens today. Aristotle did not claim that universal concepts were applicable invariably and without possible exception: in real-life situations, many universals hold generally rather than invariably.

Charles recognises the frailty of inductive logic.

In the second chapter the conversation shifts from induction to the paradox of confirmation, a derivative of inductive logic. Charles and his friend describe their difficulty in accepting the equivalence of two types of evidence for the statement, 'All ravens are black' i.e. black ravens and non-black non-ravens such as white cups. Ironically, logic is not always easy to understand and ways of comprehending the logic of paradoxes requires great leaps of imagination when one does not intuitively grasp logic's major principles.

In the third chapter Charles and his friend discuss the identity of the ship of Theseus. Theseus' ship was a trireme, a vessel more rowed than sailed, although the Greeks often had small square-rigged sails to display their colours. The timber ship, unlike modern vessels has an unusual structure that necessitates a twisted hemp rope from bow to stern. Without the rope the vessel would fall apart in the first wave. Charles is adamant he knows the ship's identity. When Charles says, how is it reasonable that the Greek authority's 'truth' is dependent on the absence of relevant information, Charles identifies the elusiveness of truth.

In chapter 4 Charles identifies self-deception as the cause of the Greek authority's plight in chapter 3. He labels his friend a self-deceiver because of his inability to identify that *a priori* knowledge has evaded him. *A priori* knowledge, that which we know by reflection alone, has the capacity to deceive because of the juxtaposition of the notion of common sense with ideas that are self-evident.

Chapter 5 finds the two friends discussing the Barber Paradox of Bertrand Russell. Charles illustrates his understanding of logic by demonstrating a *reductio ad absurdum* argument to deny the existence of the Barber. Charles identified for me something which caused me horrendous difficulty. I was unable to separate Russell's existence claim of the barber from the existence claim of Russell's set or indeed from the claim that white cups support the hypothesis that all ravens are black. Until I recognised that both Russell's set and the white cup evidence are *entailed* by principles of logic and that the barber is not entailed by anything I was unable to fully utilise paradox as a teaching strategy.

In the climax, Charles discovers himself to be delusional. The character Charles deceived himself and required a major shock to recognise his own self-deception. His loss of physical condition through sleep deprivation and a poor diet combined with a lack of exercise and excessive alcohol consumption had all taken their toll on Charles.

The metaphor of the cat represents this thesis. The ideas had been developing long before I made any commitment to genuine and scholarly enquiry. In the end none of us really has a say in whether or not we get a cat.

The Frailty of Inductive Logic

> All the evidence may point to some truth that has all the appearance of being true; but inductive reasoning is simply not valid. No strong argument can inductively assert that the sun will rise tomorrow.

It was a short journey from my house to the street where I found myself sitting, leaning against a metal handrail. The cat I'd owned since I began my solitary life was propped against my hip with one leg sticking flagpole-like in the air, giving it access to the anus it was frantically licking.

The cold steel woke me long enough to recognise my surroundings. I was safe, safe because I was unconscious and safe because of my proximity to people who knew me well enough not to pass by.

My unconsciousness served me well. I didn't witness the consequence of shallow friendships, and uncaring neighbours. My death was unobserved, the vomit clogging my airway; a mixture of stomach acid, cheap red wine, and lasagne; had the consistency necessary to resist the gravity, that should have brought salvation; and also the consistency, unfortunately, to adhere to the lining of my larynx.

Some years before, I can't recall the exact location…not now anyway. On the second Tuesday of every month we met, always the same place and time. This day was no different—except I was alone. One hour passed, and then another. I couldn't drag myself away—it was too final. Yet as final as it was, surely the only explanation embroiled death—perhaps incapacity. Yes! Perhaps incapacity, I prayed for it; with atheistic devotion. The probability of incapacity; surely it's zero. If I accept this meeting, that had taken place year after unending year, for some five decades, at exactly the same location and time, would always happen; then why wasn't he here? He should be here. He was always here. We'd made an agreement.

The certainty of our meeting had been akin to finding fire where there had been smoke. The only agreement I'd ever made with Charles was that we would always keep this agreement. In the early days, more than one girlfriend had rejected being discarded in this way and retaliated in creative ways. One such martyr-malefactor had lodged some liver, destined for the cat's bowl, into the drip tray at the bottom of the fridge. The heat from the refrigerator's cooling fins had combined with the moisture from the drip-tray, and converted the breast-like texture of the liver into a green, putrid soup. The soup, which remained undiscovered for three weeks until the fridge fell into the hole made when I ripped up the floorboards in an attempt to uncover the source of the stench.

Charles and my relationship was affirmed by a pair of qualities we each recognised in the other. One was our capacity to, as Charles would say, "speak out our arses"; and the other was an ability to enjoy each other's company. Pure and simple. Once a month for fifty years—he must be dead!

It's amazing the way your mind just fills in the gaps! The poor bastard was probably just stuck on the crapper with a dose of three-day-old curryitis and I had him in a box. Then I remembered the mobile phone I kept in my pocket deliberately pressed against the long since functionless and shrivelled remains of my manhood. Phone calls I received moved memories of a past life. I'd give him a call.

When his phone finally picked up, I heard his reassuringly familiar voice on the other end and smiled; just fleetingly, before I was aware of the crackling of the answering machine. "Damn! Damn! Damn! Damn! I hate those bloody things! He is dead!" Then, the strangest thing happened. He just turned up! Jesus was I mad. He turns up two and a half hours late for a meeting we'd kept punctually for fifty years and *he* was surprised to see *me* in a state.

In recent months, Charles had grown distant. Some great burden had fallen down upon his increasingly emaciated body, yet his cheerful countenance remained, still pleasant to be around and fiercely remote. I was always unwilling to inquire. The two of us always managed to talk non-stop for three hours. It surprises me still, that, not a word of it would I remember the next day. The feeling was like waking after a restful night's sleep.

His confession came after a few hours on the piss. He had a bloody girlfriend! At his age. "You dirty bastard", I sneered. "What are you playing at?" Why the hell was he being so coy? It came to mind, but had never been confirmed—Tuesdays were no more.

As the black box of my unconsciousness closed around me, I had a vague notion that a person was riding slowly past my body slumped against the metal rail. The haziness was more associated with the fact that this person was apparently riding *repeatedly past*. Maybe salvation would come. Perhaps she was struggling with a difficult decision—most people would ignore, with casual indifference, this individual who was clearly a drunken vagrant. Sure, since Charles had decided to exchange beer and pool for the warm embrace of my wife of thirty years, I had neglected caring for my outward appearance; almost as much as I had neglected the more basic nutritional requirements that had led to my collapse.

The feeling of familiarity would not leave—this woman on the blue bike, the tiny scar visible on the outward curve of her left calf, the calf that sailed repeatedly past my line of sight, showing a reversed question mark.

We'd often joke about its inferred rhetorical question.

It is not uncommon to find students using inductive reasoning to justify the truth of their knowledge claims. I recall a student Laura who thought it perfectly reasonable to claim that given her mice had tails that it would be reasonable that all of their offspring would have tails. She was very shocked when after five generations of in-breeding she saw mice born with no tails.

I told Laura about August Weismann's experiment: tail-docking 901 mice over 5 generations. Weismann's purpose was to refute the claims of Lamarckianism, specifically the inheritance of mutilations.

Weismann conducted an experiment not to support but to refute claims that tail docking was heritable. Science proceeds by conjecture and refutation. If the hypothesis of inheritance of acquired characteristics were true it should be capable of withstanding multiple attempts at refutation. Testing hypotheses by testing predictions deduced as consequences has greater validity than finding evidence in accord.

Charles meeting his friend on many previous Tuesdays gives no certainty to the claim that he would continue to do so.

A Paradox of Confirmation

> The problem with accepting white cup evidence is that it leads to the most appalling and unbelievably ridiculous knowledge claims.

Charles roared “Bollocks!” in response to my recent words.

“You would say that, Charles.” I replied. I could tell what was coming next…and sure enough,

“Well it is. What you just said makes absolutely no bloody sense at all.”

The afternoon was pretty typical, if you’re going to have a conversation to forget later you would want to make it about something that had no possibility for agreement or resolution. Charles constantly accused me of bull-shitting him just for the fun of seeing me squirm. Naturally my response, to his insincere accusation, was just as predictable, “It does. Charles you just have to try a little harder to make sense of it.”

“How many times have I heard that?” said Charles.

“Well probably more than once or twice but that’s how it is!” I said. After forcing Charles to buy me another beer before the happy hour ran out, he insisted that I run past him, once more, what I had just said to him that had caused him such angst.

“O.K., try me again.” Charles said, after slurping a big mouthful of Guinness.

I simply said, “All ravens are black. It makes perfect sense doesn’t it?” Charles was not too sure but indulged me as he had always done. The ravens were coming in to roost.

“Yeah well that bit I get. That wasn’t the problem. It was what you came out with next.” said Charles.

Drinking—we were both good at. It was a real competition to see who could drink more. I of course, always lost but gave it my best shot. Alcohol is usually considered a conversation lubricant; we didn’t need any help in starting a dialogue, ironically the alcohol’s depressing quality was the only thing that could get us to shut up and stagger home.

“All ravens are black, that’s the same as saying, ‘everything that isn’t black isn’t a raven’. You have that bit too don’t you?”

“Sure”, said Charles, “That makes a bit of sense, but you’re losing me fast.”

What was so hard about that, anybody could understand that. If it isn’t black it can’t be a raven because all ravens are black. If a red object flashes before your eyes so swiftly that you have no inkling what it may have been and I asked of you, was that a raven? Sure as eggs you would answer in the negative and follow your stout refutation with the evidence to hand that it couldn’t be because the object was red.

Charles commented, “This is even worse that the idea about the cat.”

We both hated cats. Getting cat crap under your fingernails, especially fresh stuff, was the most disgusting thing that can happen to a person in the normal course of events, so the idea of allegorically killing a few cats down the pub on a Tuesday afternoon in May was the most popular reason for a conversation we’d ever had.

“Nevertheless” I responded. “Come on now—one idea at a time, besides I thought you accepted the cat’s double act.”

Charles mockingly said, “Very well do continue oh great one, but instead of ‘All ravens’ make it about something I have an undeniable interest in and say—‘All Guinness is Black’.”

Naturally my willingness to oblige took minimal coaxing, friends did that for each other, after all, Guinness drinking was what we did best, besides pool there was little else to entertain two elderly men, that didn’t involve being horizontal. “All Guinness is black, is the same as saying everything that isn’t black isn’t Guinness.”

“For you”, was spat at me along with half the foam from his recently acquired glass.

After nonchalantly wiping my face I continued. “Exactly how many Guinness have you drunk over the years?”

“Jesus, I don’t know. We usually have eight each. How long have we been doing this?”

That afternoon we exposed the tally. Thirty years and two months. The tally was—well it was big—more than three hundred months. We'd had a few and went on to have a lot more until our tastes finally changed.

Practically shouting I said, "Have you seen a single Guinness that wasn't black?"

Charles answered, "Not a single one."

"There you go," I said, "The generalisation that all Guinness is black is supported by your series of observations of pints of black Guinness. Now the next bit, if everything that isn't black isn't a Guinness, and you have shown this with your observations of all these non-black things around us that are not Guinness then it is equally true that all non-black non-Guinness things are evidence for all Guinness being black."

"You did it again; you're talking out your arse! How could something that isn't Guinness prove anything at all about the Guinness itself? Just say you were some poor bastard living in deepest darkest Africa and you'd never heard of Guinness let alone seen or had the pleasure of drinking one, how could you possibly make decisions about the properties of Guinness under those circumstances?"

"Well that's the point you see, from a logic perspective it doesn't matter at all because the statement, 'All Guinness is black' is the same, it's logically equivalent to saying, 'All things that are not black are not Guinness', which is the same as saying, 'Anything that is non-Guinness and non-black' is evidence in support of the statement that all Guinness is black. Speaking of which, it's your shout. With all that gabbing you missed the close of happy hour."

Charles arrived back with the largest grin I'd ever seen and banged down in front of me a green pint. The food colouring left over from the recent Saint Patrick's Day celebrations had turned my usual drink into a rather irksome concoction but was it Guinness? Closing my eyes I took a large mouthful and concluded that it tasted green.

"So what you're suggesting is that although, 'All Guinness is black' is an acceptable generalisation there can be obvious exceptions to the rule?"

“Exactly,” said Charles, “when we claim that all mammals give birth to live young we comfortably accommodate the Echidna within the group ‘Mammal’ even though, as an egg layer, it is an exception to the rule. The generalisation stands and we accommodate the exception. In the illustration with the Guinness the generalisation, all Guinness is black is true however, we accept the possibility of drinking the odd green one for the sake of solidarity with the Irish. All Mammals give birth to live young is true in the sense that we can use it to identify animals as ‘Mammal’, in spite of the odd exception to the rule.”

“Tasmanian Tiger Snakes give birth to live young!”

“What!”

“That snake isn’t a Mammal, it’s a reptile,” I said.

“Ah yes, but the exceptions run both ways,” said Charles, “In the cases of the Echidna and the Snake we aren’t reliant on the category of live young as our only means of identification. Besides which, when the term Mammal was coined the possibility of the fanciful Echidna and Platypus was not considered.”

My mind was contemplating the abandonment of all forms of classification when I said, “Let’s hypothetically consider that the artifice of ‘species’ is removed—what do we lose? Better still, what can be gained by discarding the pretense? I believe some old and fragile arguments contradicting evolution vaporise if we accept the premise that all living things belong to the same species and that what we see is simply diversification and temporal separation of distant relatives. We become estranged from our ancestor—that is all. The reproductive incompatibility is understandable if the variations that develop simply exclude the possibility of coitus.”

Charles said, “So what you’re saying is that I’m related to a garden snail more directly than was indicated to me by my high school science teacher’s two-dimensional tree diagram.”

“In the end I have to acknowledge that the weight of evidence of the non-black non-raven object being evidence in support of the generalisation that all ravens are black is far less than the weight I can attribute to a single black raven. There being a finite number of ravens and presumably an infinite number of 'other' objects. The truthfulness of the black raven hypothesis is beyond dispute in spite of the rather alarming observation that I've also seen an albino raven in the Punchbowl Zoo and I happen to know that the under garb of the raven is grey."

My students struggled, as I did, with the notion that anything other than a raven could tell you anything about ravens.

In spite of major effort on the part of some students many came back with, "I don't get it" which simply meant to me that they were conflicted by the logic. Until Jon's encouraging engagement; then most students were able to come to terms with the paradoxical nature of Hempel's Ravens.

I believe that the student who recognises the frailty of inductive proofs begins to develop the sophisticated view of science's truthfulness. Abandoning the alternative view that science is truth.

The Ship of Theseus

> A priori knowledge, that which is known to be true by reflection alone, is self-evidently true. Sometimes self-deception and self-delusion exist in place of truthful self-recognition.

"Charles—if I were to tip this Guinness into your glass, which started empty, until my glass was empty and your glass was full, whose beer would you have; yours or mine?" I said.

As was usually the case it took but moments before we were talking about things that sent the other patrons, at the pub we chose to drink, scurrying for the far corners. Occasionally one or other of the locals or an unwary foreign backpacker would stumble headlong into the conversation. We'd entertain no interference. As soon as somebody interrupted we talked about trivial matters such as the size of the barmaid's attributes. We didn't take anything said seriously, so it was bothersome if somebody else did or tried to. We weren't interested in changing the world. We were hanging out and this was how we liked to talk.

Charles responded in the usual way, "Don't be bloody stupid, if you tip your beer in, it would still be your beer but it would be in my glass and I'd bloody-well drink it on you" Charles then said, "Look don't try and argue the toss with Guinness. It's not necessary. We were talking about ships and that is an entirely different thing. You can't analogise with beer."

"O.K. Charles, ships it is. As I was saying the Greeks memorialised Theseus' ship in recognition of the great adventure that he had undertaken. Australia, I think, did the same sort of thing with Captain James Cook's ship."

"Yes, yes, I understand that bit entirely. In fact I totally get what you're saying I just don't know the answer and that may be because the question is flawed or there is in fact no possible answer for that particular question. Run it by me again."

"Theseus' ship is cared for because of the great importance placed upon it by the Greeks but unfortunately being made of timber it begins to suffer the ravages of time. Sun and saltwater gradually chip away at the boards and staves and so the Authority takes the dramatic step of cautiously and carefully replacing timbers on the vessel, but only where and when absolutely necessary in order to maintain the integrity and likewise the seaworthiness of the ship. Year by year, one after another, timbers are replaced until it is noticed by the Authority's shipwright, whose meticulous records kept and passed down for centuries, show that with the last timber, every timber on Theseus' ship has been replaced with a new one.

Secretly, other shipwrights, all admirers of Theseus since boyhood, had 'collected' the original timbers, carefully removed from Theseus' ship. The secret shipwrights had, by hand, carefully rejuvenated each board, sanding or filling and reshaping the original timbers to construct an exact replica of Theseus' original ship from the salvaged timbers. With the removal of the last board and this board's rapid resurrection and installation, the secret shipwrights complete the reconstruction of their replica. Upon its completion the shipwrights sit back to admire their handiwork and declare that this vessel is as good as the original.

With that thought they discover, materialising before their eyes, not a replica of Theseus' ship but Theseus' ship itself. So you see, my dear friend, the Greek Authority is lovingly caring for the wrong trireme."

Charles began to slur, "Maybe so; but by implication you're not the friend I once knew because of the changes you have undergone since we became friends. If the Greeks have the wrong ship then you're not my friend."

I replied, "Ahh! But you're wrong. We continue to renew our friendship every time we meet similar to the same way that the shipwrights renewed Theseus' ship. We're not stuck in the past. If however we were not to see each other again until just before one of us dies we would most probably agree that we are no longer friends because of the changes we had experienced in isolation from each other."

"You suggest that as long as the shipwright doesn't tell the Authority that they don't have the original, the Authority will continue to think that they have the original and they would be correct. How can it be reasonable that their truth is dependent on the absence of relevant information? This would suggest that nothing is certain because of the certainty that all information is not known. Can't you see the paradox of that conclusion?"

"Is it possible that the secret shipwrights and the Authority are both correct and both have the original ship? Is it possible that this is an example of some statement being both true and false?"

"No it just means that the ignorant Authority deceives themself, and the truth of that statement is infinitely plausible. The beer you just poured into my glass is both yours and mine but if I drink it like this," Charles pauses ever so briefly to down the full pint in one draft, "you can't avail yourself of the ownership you claim. You can't drink the same beer twice in the same way you can't step in the same river twice, unless you're a really sick bastard—although I suppose, given that it is you we're talking about—you could."

Being able to sort the wheat from the chaff is important in science but sometimes 'what is what' hides, concealed behind what is only apparently true.

Take for example the occasion when a group of my Science students carefully propagated root cuttings of the endangered plant the Blue Pin-cushion (Brunonia australis). Just prior to planting cuttings back into the Kate Reed Reserve, we all, and I include myself, believed we were doing much good but decided anyway to ask the Threatened Species Unit of the Tasmanian Government if we were acting appropriately. "Do not plant your clones you will do irreparable damage to the biodiversity of the Reserve" was their response. Sometimes one Brunonia plant is not the same as another. The difference may remain unseen?

A Paradox of Self-Deception

> This self-deception and identity clouded in miasma of false beliefs and prejudices needs to be banished.

"Tuesday… Shit! I'm off. I'll see you in a little while."

As I slammed the door and left, I thought I should return and say sorry for my abrupt departure just in case my haste to leave was taken the wrong way. I could end up with more than the usual grief for coming home slightly pissed on my return. Peculiarly, I always referred to my level of intoxication as 'slightly pissed' but instead, I think, the level of intoxication was considerable.

As I entered the door facing west I saw Charles coming through the eastern access. We synchronised in movement and grasped, with uncanny timing, the pints the barmaid had placed on the counter before us. Our friendship had been of such length that we often concluded each other's sentences and, like lovers, pre-empted each other in movement and thought.

Moments before, in the full knowledge that our arrival was imminent the barmaid had pulled the pints topping them as we entered. She no longer asked if we wanted anything, merely pouring as we emptied one glass after another. She did this until, standing together, we signified our exodus.

"How you been?"

"Not bad, how about you?"

"Can't complain."

"Why the hell not, you usually do."

"Hang on a sec'", I only ever complain if I have a legitimate reason to do so… In fact, I can look you in the eye and swear I have never complained gratuitously—not even once."

Charles spat, "You know that's crap, you complain all the bloody time as if it's some game for you—it's why I like you; you stupid bastard."

I remember thinking at the time that it was quite possibly true but that I still felt hurt by the remarks. I had always considered myself a deep thinker. The deep thinking—even so—led to ambiguity that vindicated my certainty about its utilitarian use.

Charles continued, “You’re like me, you have to moan about something or you don’t feel alive.”

“*Geez* you’re full of shit.” I said, “Give me one example where I’ve moaned about anything for no apparent reason.”

Charles responded, “You can’t put me on the spot like that; I’d need a bit of time at least.”

I thought for a while and said, “It was you who put me on the spot, bringing up that I complain unnecessarily.” Now I was feeling a little disgruntled. Everybody it seemed, even my closest and dearest friend, thought I was a grumbling old fart.

Charles confirmed my fear by stating in his matter-of-fact way, “What I’m suggesting is that, if you think you never complain gratuitously, you’re deceiving yourself.”

“What! How the hell can I deceive myself?”

“Of course you can”, said Charles, “People do it all the time, ‘my arse isn’t big in these’, ‘people adore me’ et cetera et cetera.”

My response was measured, “...In order to deceive myself I would have to knowingly, intentionally deceive myself. I could be intentionally deceived by you, but I can’t knowingly deceive myself because I’d know what I was doing—surely?”

“Did the Greeks deceive themselves about the authenticity of Theseus’ ship?” said Charles.

“I perceive that they have.” I responded, “It would be true that the Greeks deceived themselves if they believe that they have Theseus’ ship, for I, like you, believe they don’t have the original vessel. I don’t believe this is what the Greeks are doing here. Their intent is to honour Theseus’ memory by caring for his ship. Whether it is or is not Theseus’ ship is a moot point. The Greeks do not know of the existence of the secret shipwrights’ ship or of its origin. The Greek authority may well view the action of the shipwrights as scurrilous upon discovering the other ship and appreciating its origin; they would no longer be in a position to deceive themselves because they would have knowledge of this alternative vessel.

They can believe they have Theseus' ship because of their interpretation of the evidence they have that confirms this view. They may well think that the shipwright fraternity have Theseus' ship but choose to continue to claim they have possession, in arrogant face-saving sedition. In this case what they would be doing is deceiving the Greek community. The shipwrights, no doubt, would reject the attempt at deception; but the Greeks, certainly, would not be deceiving themselves."

"I wouldn't dispute your eloquent position", Charles remarked, "but you are knowingly deceiving yourself because you know the truth of self-deception."

I wasn't in agreement with Charles on this point but kept my mouth shut. The arguments that start with 'it's self-evident' are self-evidently flawed.

Charles continued, "It is after all, as a concept, self-evident. Others easily detect the Greeks' self-deception; they are unaware of their own position which is visible to any and all outsiders. You may well claim that this lack of awareness is evidence of the absence of the knowledge required for self-deception; however, the Greek's knowledge of deception is beyond question, consider Epeius' Trojan horse.

Anyone with the capacity to deceive others has the capacity to deceive themselves by selecting when they choose to acknowledge the possibility of their own frailty to self-deception."

The principle, to purge or cleanse my soul of its fake beliefs, seeming knowledge, and prejudices—because of my commitment to the Socratic principle of doubting my own convictions floated mercilessly to the surface of my mind and I was struck by the thought that neither the Greeks nor the Shipwrights possess Theseus' trireme because although the fir timbers were exchanged the hemp was 'replaced' to prevent the ship's back from breaking.

My students, for telling them to not 'believe' anything, chastise me.

When I say, "do not believe anything I say", they sometimes revolt. It is exceedingly difficult for my students simply to not just believe and sometimes it might be best for them to simply accept stated facts. My authority as a teacher comes with great responsibility. Professor Delbourgo once chastised me for asking my students not to believe anything I say. He told me to, "just tell your students the scientific truth". I said to the Professor I thought I was when I said that I was as uncertain as they were about the truthfulness of some ideas within science.

Reductio Arguments

> Isn't it futile if we use *reductio ad absurdum* argument to demolish a premise that could equally demolish the principle of the Law of contradiction by the preferential treatment we may choose to give a different premise.

"If I shave everyone who doesn't shave themselves who shaves me?" I said, as once again we found ourselves sharing a dreary Tuesday afternoon.

The stroll down to the local seemed to take forever today, finding the old bridge closed for sand-blasting meant walking back the way I'd come—of course moaning to myself the whole way. Being a smart-arse, I'd also thought I'd stumble upon a short cut—how wrong I was—first ending in a ship-yard and then a scrap-merchant's yard I didn't know existed. Even so, the scrap-yard had apparently been no more than eight hundred metres from my front door for a considerable amount of time; given the colossal amount of metallic detritus.

The walk, first back toward the sand-blasters, before returning along the path I'd originally taken, then back toward my own house, seemed like a tremendous waste of time; neglecting the reassurance of being able to take my one true path toward my desired destination.

By the time I sat on my stool the dull ache usually felt in my calves, after the walk down, was a raging torment. The distress soon dulled as the conversation with my close friend, waiting patiently for me to catch my breath, pursued other feelings.

"You're late."

"Not by much," I said finally.

"How come," said Charles.

"You know the old bridge is being rejuvenated – it's been looking a bit rusty – there's a crew down there right now blasting all the crud off it—ready for painting I suppose."

Charles said, “I kind of liked the flaky brown look the bridge had developed; it looked rather organic—you know…alive.”

We both agreed that the newer substitute, built to take the increasing flow of traffic in the seventies, lacked appeal. Why is it that the Engineers have their taste in their arse? Great slabs of concrete and steel are no substitute for the elegant ornamental bridges built by our Victorian forebears.

That beautiful old bridge, with its iron scabs and festering malignancies held the attention of all who walked down the short flight of steps required to see where the bridge-builders do the majority of their craft. Nowadays all bridges, even the Victorian ones, look the same from above, a sea of black-tack and crash-barriers.

I’ve heard it said that it is ‘smell’ that binds us to our memories—this place had the hot smell of rubbed steel, intermingled with the smell of the decaying vegetation—if the tide was out—and it was that day.

The rice grass that clogged the river banks captured the flotsam and jetsam of rural waste washed downstream, to rot slowly, anaerobically, in the cool river water.

“Still it shouldn’t have taken that long to walk the road down to the highway.”

“I took a short-cut,” I said “and ended up in a scrap-yard after a few minutes down in amongst the slipped boats.”

Charles spurted, “Typical…what you were saying before about the man-sculpting—where was it going?”

“It’s referred to sometimes as the Barber of Seville,” I said, “Simply put who shaves the barber who shaves every man in Seville who doesn’t shave himself.”

After the briefest of pauses Charles said, “It’s very apparent that there can’t be such a barber, unless, we decide there ought to be.”

“Why ought to?” I said.

“It’s like the unicorn; there may not be such a creature, but life would be pretty dull if we didn’t look for the unfeasible. Even knowing that hunting unicorns or Tasmanian Tigers, for that matter, is futile, it's purposeful to participate in hunts of that nature. The human mind is fortified by the knowledge that it has the power to create, especially to create that which cannot exist."

"Why can't such a barber exist?" I said.

"The suggestion of such a barber leads to a contradiction. It's because I'm logically led to a contradiction that the original idea of the plausible existence is false because we exclude the probability of logical contradictions as a way of life."

"Wouldn't you say though, that the original thought of the exclusion of logical contradictions leading to the contradiction generated by an eminently plausible barber should lead, by the same logic, to the exclusion of the rejection of that Law of Non-contradiction?"

"It's not that easy to dismiss the foundation of logic that has guided progress for the last two thousand years," said Charles. "The Barber has the briefest of lives, merely one hundred years or so old. It's unlikely we are going to say, 'to hell with it' let's accept all contradictions."

I remarked, "What are the consequences?"

"In the case of our Barber it seems of little consequence to accept the plausibility of such a character that when analysed generates a contradiction, but in the case of the paradox of the liar, the view that something can be both true and false is likely to be cataclysmic since it implicates everything."

"I bet you can't think of any examples where true contradictions are accepted in reality as opposed to being rejected because of some logical inference?"

"Yeah, sure I can!" said Charles, "Do you recollect the notion by a politician that the teachers of our Nation should be paid bonuses based on evidence that they had improved the lot of their charges? Consider this—that a Protagonist decides to sue her teachers that don't receive a bonus on the basis that they receive their pay on false pretences, having not taught this student in an exemplary way, as recognised by the teacher's employer.

Given the certainty of litigation for failure to stimulate sufficient learning some teachers unite, agreeing to avoid teaching their students anything of value so that the students are ignorant of their own shortcomings, instead some teachers assess to inflate the students' results to indicate to the employer of the teachers that the students had learnt something of value, leading to the payment of bonuses to these teachers.

Given that some of their students are naturally endowed with an innate intelligence and are able to deduce the consequence of introducing such a bonus scheme, they chose to sue their teacher's employer on the basis that their teachers must be failing to teach yet assessing to receive bonuses. They are able to sue on the basis that the education system has failed to deliver what is promised due to ineptitude of the employed teacher or sue the teacher's employer if their teacher manages to, on paper, improve their lot, on the basis that the results must be unmitigated lies."

"Of course the alternative exists that good teachers will teach effectively and produce warranted assessments and you may argue that it would mean that some of the high achieving students are honestly earning their results and that this may provide a defence against the legal action taken by the student. These teachers are due 'just recognition' you would claim. Yet, the few teachers who choose, for financial reasons, to inflate their results must do so beyond the reach of these honest individuals and therefore regardless of the performance of the competent teachers and students, the less able students and the minority of teachers capable of falsifying student assessments will be the temporary winners."

"So, you see what choice does an honest teacher have but to lie," responded Charles.

"Surely an education system is learned enough to recognise the error in their conjecture and make the decision to abandon bonus pay? Then again perhaps not—logic is only one way to make and justify a decision." I said.

Although Popper would claim that refutation is better than confirmation, with its probabilistic nature, to refute an idea because a logical contradiction has been deduced as a logical consequence of a theory would deny the existence of the Hawaiian Island chain.

My students in grade ten, especially students like Rose, Manon, Robert and Elsie were unwilling to reject tectonic theory because of the existence of volcanoes thousands of kilometres from a tectonic plate boundary. They all accepted the compromise to tectonic theory willingly and readily. An adapted and sophisticated tectonic theory includes hot-spot volcanism.

The choice to reject or modify a theory is not as simple as it may seem. The work of Brewer and Chinn (1994) indicates seven responses to anomalous data. Rejection and modification are only two of seven possible responses.

The Climax

> Having a mind for paradox, a crafty way of manipulating them playfully, moulding them and shaping them dextrously is essential for any paradox scholar or indeed any science student.

Lying dormant on the ground, gripping a crumpled paperback, I stared mindlessly across the cobbled pedestrian pathway at the delivery van waiting outside the deli for the morning delivery of fresh bread. The smell of the bread was irresistible and if I had the right driver he'd toss a loaf, still warm, down to me; the price for which was, giving him a hand to carry in the crates.

'This' driver sat limp in the van listening to the dogs and scanning the local paper. My vision of this scene was confused because I could see someone seated against the side of the van and I recall now what a strange thing it seemed. The van, painted in French red-white-blue vertical stripes, was highly polished; the symbol of the artisans who shaped the French pastries and ornate loaves I bought that never made it home. Somehow this character had fallen asleep against the side of the bread truck. He looked familiar; but without my glasses, they must still be on the table next to my bed, I couldn't make out more than the gender and attitude of this stranger. His cat was vigorously trying to attract his attention, mewing and rubbing itself against him to no avail.

The poor chap didn't look that great. I felt a kinship for this down-n-outer that stirred me to rise. As I struggled to my feet the chap stood and made his way to greet me, reaching out his hand in a gesture of goodwill. The pain in my wrist as I rammed my hand directly into the truck's stark-white painted side brought home the reality that this sorry excuse for humanity, standing before me now, was the same person who stood before me every morning in my bathroom.

Eventually I could hear the truck's driver yelling.

"Piss off you dirty old bastard, I have to clean the marks you're leaving with your greasy mitts."

I staggered back against the rail and used it to steady myself as I climbed the steep stone steps up to my flat. The book's cover I gripped was sloughing off in my hands—wet from perspiration. Severn bent down to pick up the book's contents as it fell to the floor.

"Why do you insist on carrying that book everywhere you go, it's starting to smell bad—it's not the bible you know?"

"What's that supposed to mean, how many people do you know carry a copy of the bible with them on their travels?" I asked. The remainder of the conversation was left hanging, it could wait—after all it had been so long since we'd had a real conversation. I sat on the comfortable and unbearably ugly cane divan in the sunshine of the early morning pondering what had happened in the last ten years of my life. Not that much.

As Severn sat down next to me and I looked into her warm eyes, the stern look she'd given me first had disappeared and been replaced by the familiar inviting look that had attracted my attention some half century ago. Our bodies become flaccid sacks of skin and bone but the eyes remain unblemished, albeit surrounded by sentinels of wrinkles. The eyes I looked at were the same eyes I had seen for the first time when in my early twenties. If I stared hard enough all that had happened in the intervening years would disappear.

"What are you doing?" whined Severn.

"Just admiring the woman I married and love—you know…you look pretty good for an old woman."

"Now you are lying. What kind of a back-handed compliment is that anyway? I can always tell when you lie to me you know—I always could, in spite of how hard you tried to cover your tracks."

That comment bit deep and I sat silent for too long—confessing the guilt that had buried itself in layers of half-truths and blurred memories. "All Men are Liars," I said.

"Not all men but you just happen to be one of them," Severn replied.

"Cup of tea?" I said.

"Two!"

It was always two. As I poured the boiling water into the pot I noticed 'that bloody cat' as the nameless wretch was always referred to, crunching on the remnants of last night's dinner. Cats always had the capacity to track down people who hated them and weasel a way into their lives. Both of us hadn't the inclination to get rid of it and it had remained with us for so long that its origin was now vapour. All we knew was that neither of us would get a cat.

I poured two cups of tea in the 'Albert' and carried the tray laden with pastries out to the verandah; Severn was staring into the distance at the grey clouds that would bring the rain in the afternoon.

She said, "Charles why are you using the good cups?"

"What do you want—to save them until we're old?" I said. "I felt like it. It feels like a special occasion. What day is it?"

"Wednesday," said Severn. "When I saw you sitting waiting for the truck this morning I thought you looked a bit strange. Didn't you come home last night? You know I really am bothered by your staying out all night, I don't mind you going off by yourself, but I'd like to know you're O.K.—I must have ridden past you ten times – calling your name all the while. At first glance I thought you were dead, you were staring straight ahead clutching that damn book—I rode off when you started spluttering at me."

"It's alright I don't think I will need to do that anymore." I reached across and swapped my torn and tattered copy of L.W.'s Tractatus for a custard filled pastry and a cup of tea.

"I don't think I need to carry it anymore."

Living a thesis whilst raising a family of three boys and trying to maintain a semblance of a normal relationship is hard. I never really thought I wanted to write a thesis but it comes with the territory, and I didn't have the heart to throw it out into the street to fend for itself.

Chapter 8 – Perception, Authority and Truth

Perception

People perceive heat as a continuum. Two fingers belonging to one person can hold opposite views about one observation of temperature. Put your index fingers into a glass of cold water and a glass of hot water and then transfer them simultaneously into a glass of warm water. On what authority can you claim to know the temperature of the water?

In my journal I wrote,

> *Two people may independently perceive the same event distinctly differently unless the observation can be quantised.*
>
> *In the case of temperature it is the expansion of mercury in the thermometer which has been calibrated. The scale is constructed from observable physical changes that are related to the scale.*
>
> *Two people therefore calibrate/relate their observations.*
>
> *Can truth be calibrated? Is truth a continuum?*
>
> *Good versus bad may well be a continuum. We calibrate these values by relating them to events we can scale. Tim McVeigh was bad to bomb Oklahoma, Mahatma Gandhi was good; Nelson Mandela was less good, in the eyes of some.*

Heisenberg says that in order to understand the system we need only observe transformations.

If I describe an as yet unknown system to a student they will create a mental image of its component parts; this I feel is the natural tendency of the human mind. If, however, I describe to the student the possible transformation that occurs and ask them to predict what would happen to some new input they could show understanding of the system without creating a possibly misleading mental image. Is it the mental images that create the misunderstanding students possess? Are they, in turn, due to teachers needing to describe a mental image of the system in question?

The images drawn in my journal indicate a my model

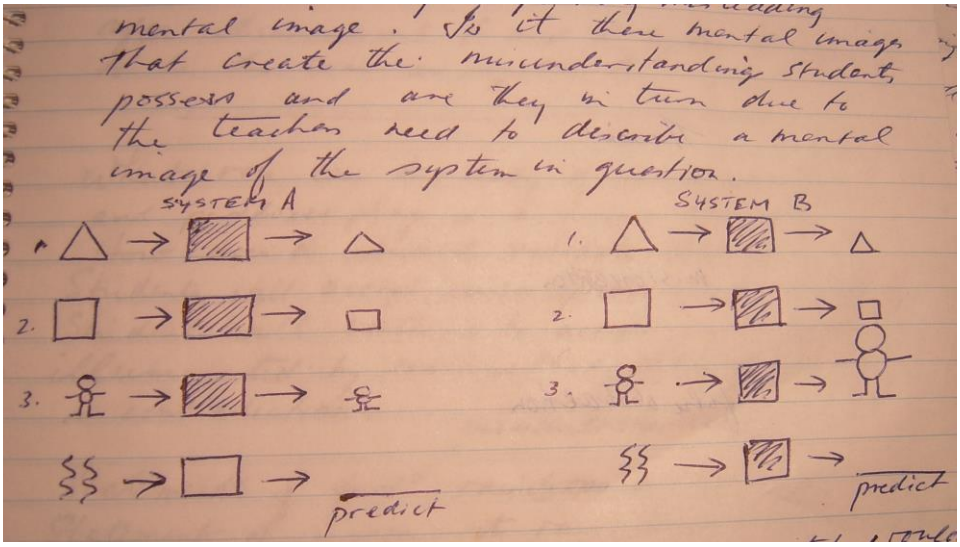

Figure - Misconceptions of students linked to images

Within System A the pattern represented would make it possible to predict the outcome. But within system B, a small number of observations of system B are not sufficient to predict with certainty. My notes say,

> *More observations are needed.*
>
> *The different outcomes allow the evidence/observations to be grouped into classes with triangles and squares in one class and people in another. What are the similarities and differences of the inputs?*
>
> *Triangles and squares are geometric shapes, with straight sides.*
>
> *People is a series of geometric shapes which represents the living human form.*
>
> *Does the input double in amplitude because it is human, is/was alive or has more than one geometric shape.*

After observations 1 and 2 system B appears to be the same as system A.

Student Misconceptions

What role can the study of misconceptions and paradoxes play in a science classroom?

How does a student validate evidence?

Students will accept misconceptions until challenged.

Students will continue to accept misconceptions even illuminated by evidence that clearly indicates a contradiction.

My journal notes above indicate that the students I was teaching had two basic misconception forms, misidentified facts, such as raindrops are tear-shaped and blue, that remain beyond question because of their limited impact on a students' broader understanding, and misconceptions of reason such as it is hot in summer because the Earth is closer to the sun. Their conclusions are false because of three reasons: invalid premises, invalid reasoning or invalid conclusions, with inductive reasoning being one significant cause.

If nature is consistent *then* no paradoxes exist. No contradictions exist in nature because as paradoxes they must be described or verbalised, they are mere creations of our human minds. I was thinking of some of the concepts I was exposing my students to.

All paradoxes must be misconceptions. Individuals will maintain these paradoxes even when illuminated by evidence that would show the abstractions false.

The Liar paradox states that all Cretans are liars. Yet Gödel's Incompleteness Theorem shows that no sets are complete.

How does a person recognise they hold a misconception? The transformations observed were not predicted or the transformations predicted are unobserved. Memes - untested

Apparently 'chaotic' gases are highly predictable. Disorder on one level presents as order on another.

Gases aren't chaotic because they are predictable.

How many misconceptions are errors in language rather than conceptual errors? Students will say, "Lead is heavier than aluminium." This is imprecise language and teachers identify this as a poor description.

A student would say that pieces of aluminium and lead, being of equal volume, the lead would be heavier. The student would also say that two pieces of the same metals, being of equal mass, the aluminium would be the greater volume. The student has trouble describing, that which they think they know and understand, in the same way that the teacher struggles.

Richard Feynman (1998), along with many others, says, very few people understand quantum mechanics (QM). Is this because of misconceptions or challenging conceptions? I find QM damn hard to fathom maybe because of my insufficient language to describe QM.

René Arcilla (1995) would argue that complexity, and there is general agreement about QM complexity, necessitates *big* language. Arcilla goes on to expose the "aporetic" nature of dialogue, "I believe that the discourse of self-definition, with which we in large part engage in dialogue with significant others, has this aporetic nature as well" (p. 169). Arcilla gives an apt warning which has monumental implications for my science classroom, "…of course, exposure to indefiniteness without any direction at all is less likely to bring selves together than to open up a divisive abyss of disorientation, fear, antagonism (op.cit.)."

Big language may well be a mechanism for the explication of complex ideas but big language may lead to the abyss feared by Arcilla. Arcilla's essay so intrigued me that I sent him an email. My email below shows my attitude toward the aporetic nature of science.

> Dear Professor
>
> Thank you for your very prompt reply.
>
> I believe the thread that connects science to philosophy is the same thread that connects science to religion.
>
> Science has inbuilt incompleteness/uncertainty/indefiniteness/inexpressibleness (See Gödel's Theorum), yet we have, "faith" (your word) that it explains the universe.
>
> Part of the uncertainty relates to the nature of the universe and part relates to an incomplete language.
>
> To illustrate, Heisenberg's uncertainty principle relates to the limit to which one can determine position and momentum simultaneously.

When Arcilla responded to this and other emails he talked of his desire to celebrate indefiniteness and uncertainty.

> Dear Mr. Lockwood,
>
> Thank you very much for your interest in my work. I doubt that I can respond satisfactorily to your comments on the article, but I'll try.
>
> The resemblance you noticed between the theme of that piece and Gödel's theorem is intriguing; however, I don't know Gödel's work at all well enough to have any idea whether you're right. Closer to what I had in mind, though, was your reference to koans. Although I am not a Zen Buddhist, and have not studied the tradition's thinking in depth, I have found in the koan genre an interesting model of an ethical discourse organized around inexpressible good. In my article, I was trying to explore the possibility of finding a place for some such discourse in the politics of recognition. Finally, I was merely trying to make the point that "exposure to indefiniteness" alone, like the aporetic moments in the Socratic dialogues, is apt to provoke destructive antagonism. To dispel that and move to something more constructive of a community, we would need to find a way, a reason, to celebrate indefiniteness.
>
> Good luck on your research.
>
> Best wishes,

René Arcilla
Associate Professor of Educational Philosophy

(R. Arcilla, 2001 personal communication)

It was Arcilla's article that led to my use of the word *aporia* as a synonym for paradox, but it was also Arcilla's article that had made me more cautious of the impact of the study of paradox by my students. I had no intention of shoving my students into an abyss.

At this point I had noted that the study of paradoxes had been a personal journey of what constitutes evidence in science, particularly valid evidence. The questions that needed to be answered were; how do we get students to step outside their common sense view of the world, how do students identify their own misconceptions, how do teachers identify student misconceptions and their own misconceptions? What is the role of critical reasoning and logical processing? Conflict with the existing memes or paradigms, including their associated assumptions, was the location for further student engagement.

The summation of the month's work was a collection of personal truisms:

Misconceptions lead to disagreement

Anomalies lead to evidence in disagreement

Paradoxes are anomalies

False abstractions lead to false logic

Theory change vs. paradigm shift

Students maintain misconceptions in the light of observable evidence

Language allows for confusion

Students don't know how scientific evidence is judged to be true

Ideas are transferred by imitation [memicly]

The need to create mental images is restrictive

Transformations are a way to understand systems

The rejection of the coexistence of opposites (LNC) [The Law of Non-contradiction more correctly called the Law of contradiction] is the basis for rational thought

The acceptance of the coexistence of opposites is the rejection of rational thought.

The Validity of Evidence

I have always believed that I am logical and with an online test of logic using a variation of the Wason Logic Test (Stangroom, 2001) I discovered that I was indeed logical—in the sense of *modus ponendo ponens* (confirming the antecedent). The lack of capacity to reject misconceptions after exposure to evidence to the contrary by some of my students suggested that these students did not possess the aptitude for logic that I possessed.

According to inductive logic I do not prove scientific theory without invoking probabilities. According to Popper, scientific theories can only be disproved, but again probabilities are involved, so technically, evidence may be found that supports an hypothesis but no absolute proof exists. This notion relates to both the work of Kuhn as well as the falsificationism of Popper and Bacon's induction but also implicates Hempel's Paradox of Confirmation, The Paradox of the Ravens. What constitutes valid evidence? How do students decide about validity? For example, the questions, 'How do you know that matter is composed of atoms?' or how can a student know, 'Seasonal weather changes occur due to the tilt of the Earth's axis'.

Do *you* believe matter is composed of atoms? If you are a scientist the answer would presumably be yes. What evidence do you have? Most of the knowledge that I know about atoms is because I trust the authority of the system that delivered that knowledge. I don't need to know everything first hand. How do I know that the Earth's rotation leads to the sun appearing to move around the Earth? How do I choose the ideas for which I require evidence versus the ideas

I am prepared to accept without evidence, relying instead on their apparent plausibility?

Sophistication leads to an increase in the number of concepts I am not prepared to accept without evidence but it also allows me to accept many concepts without feeling obliged to challenge each and every one.

My students are prepared to accept the following ideas: the greenhouse effect, ozone depletion, tectonic theory, black holes, life on other planets, Martians, revitalised fossil dinosaurs (Jurassic Park). For what concepts do I require evidence? What does the evidence I seek look like?

Examining the concept of space-time I accept the validity of the speed of light ‘c’ being fixed and not variable. What conditions would need to exist in order for the mass of a particle to appear to increase as velocity approaches c? The freedom to question the validity of the evidence comes with the increasing sophistication of the student of science. What do I question? Is the data reproducible, triangulated, statistically valid and consistent? What are the concepts that my students learn? Do I simply train my students to accept my authority with faith; to accept faithfully the concepts of science such as atomic theory? My answer is an emphatic no!

Student inquiries in science are often project-like; being about the ‘bricks of knowledge’ referred to by Henri Poincaré, rather than investigations linked to hypothetico-deductive reasoning. The phenomenon of qualified teachers memicly transferring poor explanations of supposedly well understood phenomena is commonplace. Fraser (2001) documents the inflexibility of the minds of young students indoctrinated by bad or bogus science.

To illustrate this idea, one of my teacher colleagues, an English language specialist, well read, but naïve in the ways of science told his students whilst on a trip to the wilderness that the *Aurora Australis* was a consequence of reflection from the ice in Antarctica. When I queried his explanation, with little more than a quizzical look, he confessed that the explanation was one presented to him when he was a child and without questioning the claim he was transferring the explanation memicly to his students. With minimal effort on my part with the exception of that quizzical look, he contemplated the inadequacy of reflection being an acceptable explanation and it was then that he found a better and more acceptable scientific explanation, validated by what he already understood. His sophistication had led, at an appropriate time, in a period of cognitive conflict, for him to question his previously accepted, false and clearly naïve understanding.

Both, my students and some teachers are using inductive reasoning to accept or perpetuate, memicly, bad explanations of scientific concepts. I accept this idea — those ideas — with evidenced explanations, so I'll believe anything else you say. Students do this using the logic of inductive reasoning which I have previously shown to be invalid.

When my students accept new concepts by faith alone what is it that allows them to *learn* the new concepts? Is their blind acceptance caused by my need to 'paint a picture' for my students? Can my students understand a concept without my painting for them, a mental image?

Tectonic Theory – a case study

The next two big concepts I exposed my students to during the course of their normal year would be tectonic theory and continental drift theory. What evidence exists to support these two concepts? Could I ask my students to, instead of 'blindly accepting a set of apocryphal beliefs', to challenge and examine the evidence that supports the twin concepts of continental drift and tectonic theory? I thought I should try.

A student, Beatrice, whom I had ascertained had an exceptional aptitude in logic by using the Wason Logic Test, had experienced great difficulties in forming sound relationships with peers, teachers and school administrations as a consequence of her questioning and argumentative attitude, yet she made the most remarkable progress of any student I have ever taught. Beatrice had left her previous school after having 'difficulties'. When Beatrice arrived at my school it appeared that she would repeat the established pattern. By late September Beatrice had made significant changes, as illustrated by the letter she wrote to my school principal.

> Dear Mrs H.
>
> Well, although I am sure you are not expecting this letter, and I was not expecting to write it, I am, and I hope that you make sense of what I will try and tell you. I was just sitting in my room, staring off into space, and got to thinking about school, seeing as it is only two days away. I thought about my old school, St Michael's in Devonport. And I remember how unhappy I was there, caused by the way that I was treated and the manner in which the school was run. So of course, I left, as I decided that it was not right for me to be attending a school that I hated with all my soul and where I cried at least once a day. I moved to Vista High, where I had spent one and a half years in previously. Immediately I was flabbergasted by the huge change in the way these two schools were run. I set to thinking about it, and noticed the main difference. St M's, being a private school, and much more expensive, was focused on giving students a 'better' education; you had double the amount of homework, and, basically, learnt double as much, double as quickly! Every day school was a slog; you just worked and worked, sometimes through lunchtimes in order to get an assignment in on time! I remember at one stage I had six assignments at once. I was continually stressed about completing my work on time, and the pressure on me was enormous! Because I live so far away from both Devonport and Launceston, I rarely have enough time for myself as it is. While attending St M's, I returned home at 6pm every day, when I then had to help with the housework for half an hour. After dinner I had perhaps one hour to myself in which I did my homework, before going to bed. Weekends were spent, surprise, surprise, doing more homework! So as you can see, I did not have much of a life.
>
> Besides being completely focused on schoolwork, which isn't such a bad thing in itself, St M's was a very strict school, in which no freedom was

allowed, and no independence was tolerated. I, of course, being a very independent person, did not fit in very well with this rule. Full school uniform was to be worn every day, and hardly any jewellery was allowed, including nail and toe polish! Numerous times I got in trouble for wearing my hair out in maths! Another point against my old school. But don't fall asleep yet, D., there is more! This school of mine simply didn't care about individuals. I was being bullied by numerous boys in my classes in grade 10, and had no friends in them, which made tolerating this much harder. Sometimes I was reduced to tears. So I did what any girl with sense would do, went to the vice-principal and asked to change classes. After weeks of meetings with this woman, wasted lunchtimes on my part, and undergoing the interrogations and questions, I was refused. And why? Because of course, if they let me change classes, then they would have to let everyone else change classes too…the oldest excuse in the book. When confronted with the problem of my being bullied, they simply said to talk to my class teachers about this problem, not realising that this would make the bullies more angry, and sometimes it is simply better to just avoid the bullies, and they will leave you alone.

Well you are probably getting pretty sick of my whining and complaining about this school, and asking 'why is she telling me this? What is the point?' Well, Dianne (if you don't mind me calling you this), I am making an effort to compare these two schools, although I have to admit, I am taking a while aren't I?

Anyway. The first difference I noticed was the ease in which I could change classes at Prospect. Mr C. let me do it with no trouble at all; all I had to do was bring a note of permission from my parents. And throughout the many weeks to follow, I noticed that while St M's focused on schoolwork, Vista focused on the individual, what was happening 'upstairs'. Vista genially cared about you, about how your family situation is, about what your potential as a person is, and if you are a little different, then that's okay, just as long as you continue to complete your schoolwork.

This is a great school, Dianne, I think developing the personality of a person is much more important than developing your intellect, because, most of all, it makes you happy! And being happy is the most important thing in life. Now I have much more time to myself on weekends, so now instead of doing homework, I can make flairs out of my trousers (much to my mother's horror), write more creative stories, and paint more often.

Also, I feel that the teachers care about me, unlike at St M's For instance, when I had an infected belly button from getting it pierced I talked to Mr Lockwood about it and he advised me to go immediately to a doctor. He said that if I couldn't pay for it, he would. Now that is caring! And it is so easy to just chat to your teachers about nothing, and feel like you are on equal terms with them instead of feeling like you were inferior, and constantly being monitored and controlled (as the situation for me was like at St M's).

Another example that I would love to tell you about is my attitude and solution towards science. I hate it. I detest science, and have since grade 5. Unfortunately for me, Mum had decided that I had to complete grade 10 science, even if I didn't continue with it in college. But I put my foot down, and completely refused to do any work at all in science. Mr Lockwood, try as he might, could not get me to do anything. Now at any other school, Dianne, I would have received multiple detentions and got kicked out of the class. But instead, Mr Lockwood took me aside one day and said: "Beatrice., you hate science don't you?" I of course answered affirmative. He replied, "but you love writing and thinking about things?" I said yes again. "Well how would you feel about doing some work different from the rest of the class, which would include writing and thinking about things, but also allow me to assess you in science?" I was doubtful at first, because my opinion was that anything that was science was terrible, but after my first piece of work that included working out a paradox in writing, I was hooked. So now I look forward to my science lessons as my favourites, and will be (hopefully!) passed in this subject. But even if I was not being marked for this work, I would still do it, because I really enjoy it, and have learnt heaps, which I also enjoy doing! Now I plan to keep up philosophy class in college if there is one available, so hooked am I!

Of course, there are many other things that I love at this school, and a couple which infuriate me (which I won't mention), and I thought it was important that I tell you this, because I would hate for Vistas education system to change. I wanted to tell you the great things about your school so that you know that Vista is a really successful school in meeting individual's requirements and making your students happy!

Yours sincerely

Beatrice

Most of my students, to my great annoyance, accept my statements unquestioningly, Beatrice didn't. As an example she rejected a statement that I put to her that, 'All vitamins are a waste of money'. She rejected the generalisation and substituted the restricted version that some vitamins may be a waste of money. Beatrice asked me, "What evidence do you have to support that statement." A very good question indeed, the formulation of such questions was the outcome that I intended for all my students.

Beatrice and I continued to inquire into aspects of science. We discussed outside the classroom such questions as, do extra-solar planets exist and can life exist elsewhere in the universe?

Most of my younger students were unaware that a body of evidence supports scientific theories and were of the opinion that they were proven essentially using a 'court-of-law model'. My young students had based their faith in scientific theories on the relationship, an authoritative one, which I had established as a necessary path to learning. My students believed theories were beyond questioning because they were proven to an extraordinary degree. Beatrice was a rare exception but thankfully there are more and more students like Beatrice willing to challenge their teacher's claims and his science.

The Role of Authority and the Nature of Science

John Webb (Webb et al., 2001) was interviewed on ‘Lateline’, The Australian Broadcasting Commission (A.B.C.) late night news program, suggesting that one of the fundamental constants of physics, the fine structure constant, α, was in fact not constant. The appearance of scientists on television is now an everyday event, occasionally an unhelpful one for teachers of science. Webb did not reappear on the A.B.C.’s ‘Lateline’ when his claim was rejected after the collection of more evidence.

My student Kate asked a question linked to preparation for a debate that she was going to attend later on that week. Kate’s question was, “Should meat-eaters feel guilty? If everyone in the world became a vegetarian, the grain normally fed to fatten cattle (60kg/annum) could be given to every currently starving person.”

My first instinct was that there must be a right or wrong answer to this philosophical question. The two steps I took were to re-write the question and to delineate the question by finding meanings of key words. Both of these processes were to find assumptions. The authority of the questioner drives the response of individual students toward particular assumptions. This would necessarily be the role of the advocates in a debate, affecting change in the audience’s assumptions to be congruent with their own viewpoint.

Kate’s statement for analysis was, if the western world became vegetarian then the starving, in the developing world, would have adequate food. Posed as, “should meat eaters feel guilty”.

I am inclined toward the view that conclusive evidence for any philosophical position is impossible. Each potential response is linked to a set of assumptions. For example if it is assumed that offence is from a legal point of view then currently it would not be illegal in western countries to consume meat and therefore an offence cannot be committed, and consequently no guilt ought be felt. The ‘moral’ guilt of the meat-eater may be based on ‘rightness’ but is nevertheless philosophical and therefore indeterminate. There is no ethical reason to assume the ‘guilty meat-eater’. Kate believed this question was a paradox because the two conclusions; starving people and forced vegetarianism, were unacceptable. The consequence of the act of enforcing vegetarianism on the western world would not lead to extra grain being available for members of the developing world because the grain currently grown for cattle is not free of charge. It would be true that the farmers currently producing cattle feed would find other crops to support their businesses.

Webb’s ‘variable fine structure constant’ presents a similar dilemma. When should new scientific discoveries be presented to the public? There is no doubt that each new fragment of evidence whether consequently validated or invalidated by future evidence should be published in peer-reviewed journals. The assumption set of the trained scientist is different from the general public. In this particular example, few members of the general public would have understood what Webb was on about and therefore the early publication of this evidence caused minimal affront. Other examples such as, hormone replacement therapy (HRT) being linked to cancer or a breast cancer cluster associated with an ABC studio did cause considerable anguish to many because of the more familiar context. Scientific literacy is fundamentally not content driven but instead linked to the nature of science and evidence interpretation and consequently for scientific literacy of the broader community to improve there is a need to improve the communities capacity for logical analysis.

Thomas Kuhn’s “Scientific Revolutions” (T. S. Kuhn, 1996) like the work of Quine and Popper resonated strongly with my own thoughts and provided the framework for understanding paradigms in science and the usefulness of paradox as a learning strategy. On the back of conversations with Professor Mark Colyvan and my own students I developed an appreciation that the word paradigm was as duplicitous as the paradoxes I was studying. Kuhn himself states that the word paradigm may be read as many other words. It was Kuhn’s comment on the authority of teachers that cemented and reinforced my habit of calculatingly and forcefully undermining my own authority—aphoristically uttering, "Never believe anything I say."

Kuhn (1996) claimed that students of science must accept the authority of teachers given the reliance upon applications of science as confirmation of theory. "Given the slightest reason for doing so, the man who reads a science text can easily take the applications to be evidence for the theory, the reasons why it ought to be believed. But science students accept theories on the authority of teacher and text, not because of evidence" (p. 80). Kuhn asks, "What alternatives have they, or what competences?" (loc. cit.)

The logical alternative for my students is that they not believe on the basis of my authority. The case of Beatrice referred to earlier, showed that some rebellious students appear naturally inclined not to believe on the basis of authority. I tried to minimise my students' reliance on my authority as a means to accept theories, directing my efforts toward my students developing skills in logical analysis. Undermining my own authority deliberately, with my statement 'Never believe anything I say' is a counter-intuitive or paradoxical teaching strategy. The authority of science is the rejection of its own authority; the abdication of the privileged position. The authority of science instead lies not with the advocates but with the evidence itself.

To teach the assessment and interpretation of evidence is the role of the science teacher. How is it possible to abdicate my privileged position of authority? Shifting my students' attention to the truthfulness of the evidence rather than the power of authority was a *difficult* proposition. Unravelling the concept of truth is a *very difficult* proposition.

Truth

> Almost always the men who achieve these fundamental inventions of a new paradigm have been either very young or very new to the field whose paradigm they change. (T. S. Kuhn, 1996)

The individuals referred to by Kuhn have not accepted the authority of the paradigm advocates. They have re-examined the evidence and in particular the counter-instances or anomalous observations that have failed the congruence test with the existing paradigm.

I tried identifying the grounds for my students' beliefs. Were they focussed on the evidence? *Faith* in authority was not the science way. Faith was after all the unsubstantiated acceptance of dogma, in other words belief *without* evidence. Thomas Kuhn's position was that students had faith in the concepts in science. I was convinced of the truthfulness of my own scientific knowledge by *not* accepting the authority of other scientists. Science is not so much what we know but how we know—the process. My difficulty lay with teaching my students a more sophisticated view of science.

Kuhn viewed thought experiments and other philosophical techniques as essential components of new scientific paradigms. Kuhn cites the examples of Lyell, Copernicus, Newton, Lavoisier, and Einstein as revolutionary scientists because of their acceptance of philosophical inquiry as an essential attribute of a scientist.

The date, September 11 2001 is firmly etched into world consciousness. At 10:45pm (Eastern Standard Time) I witnessed, on the late night news broadcast, planes crash into the Twin Towers of the World Trade Organisation in New York and The Pentagon in Washington. My journal notes of the time understate the reality which we now live with.

> *This is an internationally significant event that may ignite long term change.*

The, "long term change" I referred to has regularly been referred to by public figures as a paradigm shift.

A number of directions started to emerge, one of which was into a passage of my ever expanding labyrinth of seemingly peripheral reading. It may well be a journey taken by most beginning researchers however it was more than a little germane because of the developing association of paradoxes and labyrinths.

The Truthfulness of Science

I held positive scepticism as the means to acquire a greater appreciation of conceptual knowledge. My research originally was to include formal interviews with sets of students, teachers of science and lay-people. I deemed the formality unnecessary because of the depth of the informal conversations. I believed the process of formalising interviews would change the outcome. The measurement would unavoidably impact upon the participants. I therefore chose the clandestine approach and took the opportunity to discover, what I could discover as it arose; and arise it did with great regularity.

Kieran Egan's (1997) book, *The Educated Mind* and Michael Matthews' (1994) *Science Teaching: The Role of History and Philosophy of Science* were the first forays of my classically science trained mind into post-modernism. My view as an undergraduate centred on understanding science and not the interpretation of science. I certainly did not believe I had to interpret anything — I was learning the concepts and I thought, at that time, they were truth.

Matthews' book indicated the clear view, 'history aids science teaching' but that this type of history is viewed differently from Historian histories, history, which is the building up of small details to posit a true reflection of the past. Historians choose which small details to include and which to omit. The socio-political climate necessarily influences them. The milieu which we now live with, influences to some degree, all historians. Historians, similarly to scientists, test their hypotheses by examining evidence; in the Historian's case historical evidence. Examination however, is always an interpretation of the speaker or author's intentions. Is it truth that is sort by historians?

By chance, as I was reading Matthews, I met Australian Historian, Professor Phillip Hughes AO. The Tasmanian Government commissioned Hughes to assess the progress of the Tasmanian Curriculum, the so-called New Essential Learnings (N.E.L.s). I inquired with Professor Hughes about my view that science and history were different in nature because of the testability of scientific concepts. I claimed that history was open because of the emphasis on, principally, interpretation of documentation and witness accounts. He answered that thinking in science and thinking in history were different but both were equally valid or truthful within their own context. Hughes did not claim he possessed the truth he told me his historical claims were truthful and therefore valid. In the same way I thought my scientific claims possessed truthfulness and thereby, validity.

Hughes' comments encouraged me to read, *Three German Views: Hermeneutics vs Science* by Hans Georg Gadamer and others (Gadamer, Keutner, Connolly, Specht, & Stegmüller, 1988). It was this book and others like it that began to force a reconsideration of the assumptions I had made about my own science knowledge. I trade my certainty about science's truth for a heightened sense of positive scepticism that did not detract from the truthfulness I saw in my scientific knowledge.

The Moon Hoax

This "heightened sense" can be illuminated by exploring what happened in my mind as a consequence of reading a Victorian novel called, *The Moon Hoax* (Locke & Nicollet, 1975). The novel describes an evident hoax but it remained uncertain, in my own mind, whether the hoax was perpetrated against the readers of the New York Sun (a penny newspaper where the hoax apparently appeared in 1835) or against me as I read the Victorian novel.

The novel records a hoax perpetrated against readers of a penny tabloid, asserting that Sir William Herschel had discovered creatures on the surface of the moon, the story was presented in such a way that the author led me to believe that this event had actually taken place and that the readers of the New York Sun had indeed been duped by the newspaper's reporter. Because of the lengthy delays between the publication of the tabloid, printed cheaply for consumption by the masses and the arrival of more expensive and 'proper' newspapers from the Continent the hoax gained support and when eventually the papers, such as the London Times, did arrive people vigorously denied any attempted refutation of the hoax that was to occur after the arrival of the truth as represented by the Continental newspapers.

The blurring of the lines of truth reinforced my need for recognising my own assumptions about truth. Alfred Tarski's, *Truth-Theoretic Semantics* was flagged for future exploration.

In Augustus De Morgan's (2007) book, *A Budget of Paradoxes* he gives a believable account of the Moon Hoax. (pp. I, 326-327 & II, 131-133) De Morgan refers to this story as the, "Herschel Hoax" after Sir John Herschel whose telescope, at the Cape of Good Hope, was implicated in the story. De Morgan originally laid the creation of the story at the feet of Mr Nicollet. According to De Morgan, Richard Adams Locke, the Editor of the Sun Newspaper, claimed authorship of the story to ensure the deception. In later editions of *A Budget of Paradoxes*, De Morgan withdrew his claim against Nicollet because of a lack of evidence, "…but there does not seem to be any very tangible evidence to connect him to the story", although the plausibility of Nicollet's motive for the hoax remains.

Falsificationism

I read Karl Popper and Mark Notturno's (1994) *The Myth of the Framework: in Defence of Science and Rationality*, it was clear that the Principle of Falsification was central to my own view of the progress of science and my plans to improve my own science teaching program.

I thought of science as an expanding body of knowledge *and* a process. Science involves the falsification of existing theories, intuitive leaps into the unknown, aesthetic completeness, beauty in new theories, empiricism and rational thought.

Science teaching involves the sharing of explanations or the 'whys'. Why do children believe the stories I share with them? Which stories do they reject?

Why do they accept or reject individual stories? Is it my authority as their teacher that compels them?

Why do I accept certain stories? Perhaps it is because of what William James said; it counts as truth in proportion to the gratification of my own existing beliefs.

I needed more evident reasons, than my students, to accept or reject scientific notions. Barbara Koslowski's (1996) *Theory and Evidence* supplied the foundation of my understanding of what I needed to do to support my students' development of their scientific understandings.

Koslowski provided me with a framework for deciding what I ought to teach students in order for them to reason scientifically.

Koslowski was a graduate student of Jerome Bruner, she acknowledges his role in stimulating her research in the acknowledgement section of her aforementioned book. It was Bruner's quoted maxim, "Given half a chance, eighty percent of the population can score above the mean" (Koslowski, 1996, p. xi). Koslowski credits this quote as the stimulus for her to think outside the square and support constrained scepticism as a fundamentally pivotal aspect of scientific reasoning. Therefore, according to Koslowski, constrained scepticism is essential for the teaching of scientific reasoning.

Koslowski's book opened up the research field of causal reasoning. I was lead to authors such as Leona Schauble (1990), Deanna Kuhn (1989), and the earlier work of Child Psychologist Jean Piaget (Cf. Inhelder & Piaget, 1958, 1964; Papert, 1999; Piaget, 1950, 2003).

Humean empiricism and logical positivism were undoubtedly, in my mind at that time, the roots of my tree of scientific knowledge.

The Role of Causal Mechanisms

It was Piaget's (2003) comment that, "Young children are indifferent to causal mechanism", that stimulated both Koslowski and myself into further action. I had been troubled by my students' inability to articulate their conclusions to research they had undertaken. It appeared that my students were aware of causation but were having difficulties in expressing themselves.

The absence of a language to express theory, evidence and causal mechanisms may have been where the problems lay for my students. Koslowski was convinced that 4 and 5 year-old children could invoke causal mechanisms. My own children confirm that this happens much earlier still. My eldest son Morgan asked, when he was two years old, where the first pea seed came from. We planted seeds in the second season from seed collected after the first harvest. Morgan needed to explain this apparent paradox of infinite regress. A question such as this would simply fail to emerge if causal reasoning was absent from the minds of young children.

Koslowski's criticism of Piaget was that he had used the empiricism of David Hume as the basis of his analysis. The Humean approach, Hume's postulated objective scientific method, was using a theory independent approach. Koslowski believed this approach was flawed. Hume believed that causation relied upon just three measures: priority (one event preceding another), contiguity (direct contact between events) and covariation (one event always varying with another event). Koslowski showed that what appeared to Piaget and others to be the poor reasoning of adolescents was rather a consequence of the lack of acknowledgement of the role of mechanism and theory in producing explanations of experimental data.

Koslowski suggested to me that my theory independent science teaching practice caused poor student reasoning.

It seemed necessary to inquire into the philosophy of John Stuart Mill as an extension of my examination of David Hume's empiricism but in addition I read Karl Popper, Willard Quine, Paul Feyerabend, Alfred Tarski, Imre Lakatos and Richard Rorty. My mind map, produced at the time, follows.

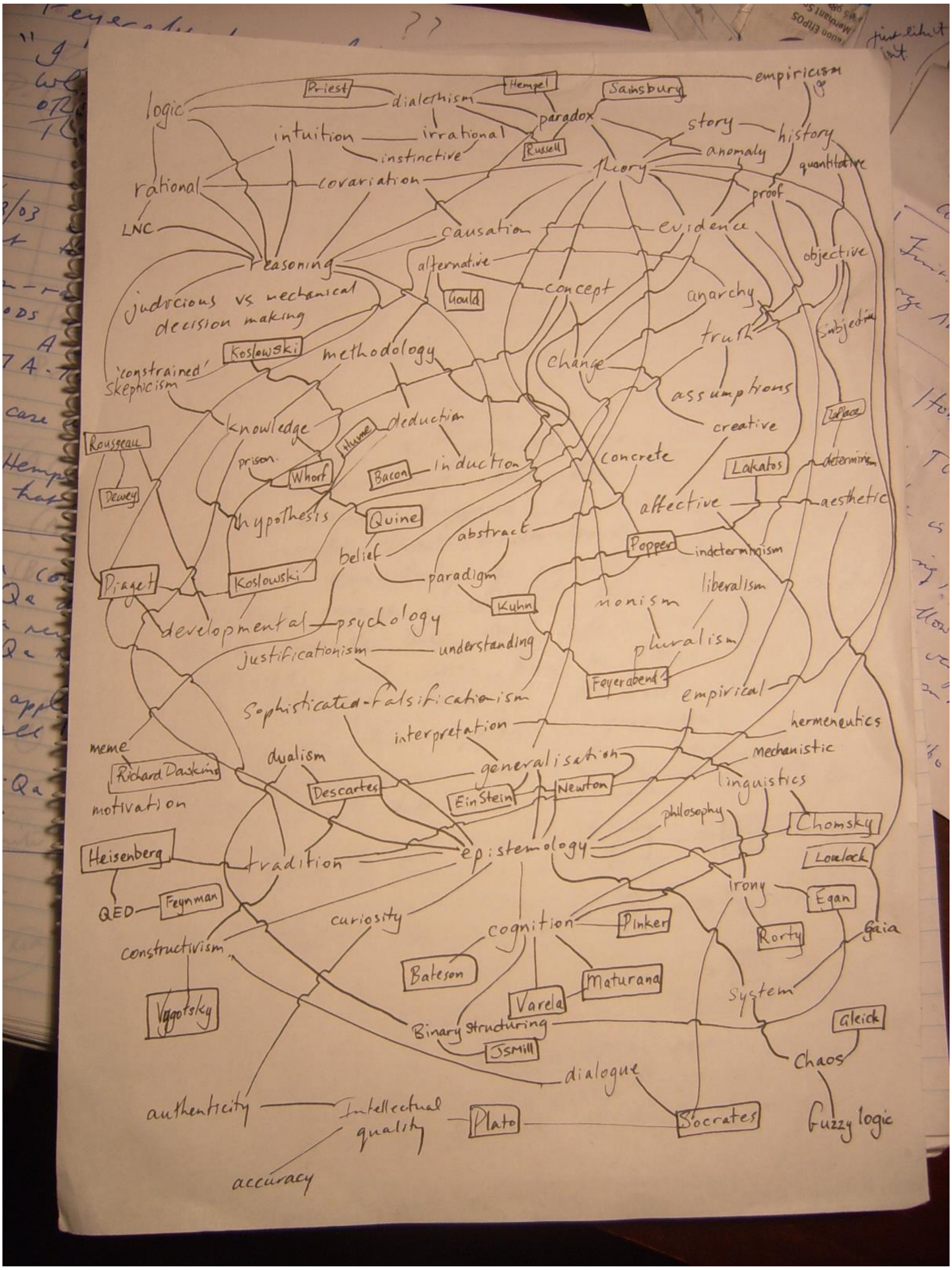

Figure 1 - Mind Map Relating Significant Authors

What do high school students understand about the nature of evidence in science? How can the study of alternative conceptions aid in students' understanding of the role of evidence in conceptual change? Can paradoxes and scientific anomalies lead to conceptual change in students? What is the role of neural maturation on students' ability of rationally analysing scientific evidence?

I was seeing an unresolved tension in my own philosophy. On the one hand, I acknowledge the positivist leanings I still value but Rorty lured me with his pragmatism. John Dewey and Ludwig Wittgenstein like Rorty had earlier said that the epistemology of according theory a higher value than experience was the mistake of modern philosophy. I acknowledged in my journal that the expectation that I placed on students was that they would select from competing views.

> *Competing Views*
>
> *Good science doesn't involve only falsificationism but also justificationism.*

My own maxim, frequently expressed to my students, had been that you can falsify a scientific hypothesis but you could never prove a scientific hypothesis. This was an example of the ease with which one slipped into competing views.

Interviews with Students – the nature of evidence

I interviewed five students in an attempt to validate, in my own mind, the use of interviews as part of my research. As was mentioned before, I deemed this process to be too costly. It was time consuming, difficult to manage and ultimately unsatisfactory as a preferred strategy. In comparison, the evidence generated by the clandestine approach I chose later was illuminating. Notwithstanding this, interviews were informative.

The questions to which I wished to find an answer were: What is science in the minds of my young students, and how crucial is evidence to my student's understanding of science?

I sent a letter to each of the original participants requesting a follow up to our conversation. Four of the five original participants participated in the second conversation, with the fifth participant unavailable due to being out of the country. I had not spoken with the students for two years.

I asked the students thirteen questions in the first conversation and six questions in the second. I conducted the first conversation in a sound studio, the audiotapes, recorded during the conversation, were exhaustingly transcribed within one week and the students were provided with a copy for review and asked to check the transcription for accuracy. These were enthusiastic science students who willingly gave up their own free time to participate. My students were encouraged to consult their parents prior to participation. All the students, to my surprise, delighted in reading their transcript and confirmed that they were accurate. The students were amused seeing their voice in print and saw value in reflecting on our conversation.

In two conversations, pairs of students participated together. I held the first conversations at a time when all students were within 6 months of their 16^{th} birthday.

The initial questions asked were as follows:

1. Supposing two scientists disagree about what a set of results mean, how are these conflicts resolved?

2. When did you first learn about plate tectonics?

3. What did you initially think of this idea?

4. How do you consider the idea now?

5. Tell me what you think science is.

6. Do you think that thinking in science is similar or different to other subjects that you do? In addition, how is it different or similar?

7. How do you go about deciding whether or not a scientific idea is believable or not?

8. What do you think of the idea that science is an expanding body of knowledge and a process; it involves the falsification of existing theories, intuitive leaps into the unknown, aesthetic completeness, beauty in new theories and rational thought?

9. A man called Piaget, a fairly famous guy in terms of education and I know your folks would probably know about Piaget; he once said that young children are indifferent to causal mechanisms and by that he means that children can't reason because they don't understand the process of cause and effect. Do you think that he was correct?

10. What is a 'conclusion' in your mind?

11. What does it mean to reason?

12. What or how do you think students should be taught in order to teach them to reason scientifically?

13. How do you know the difference between good and bad evidence?

The second interview questions were:

1. Did you study science in years 11 and 12?

2. What did you study?

3. Did you examine evidence in these subjects?

4. How do you know the difference between good and bad evidence?

5. Did your teachers ask you to reason? Can you give examples?

6. What do you remember about plate tectonics?

Prior to the interviews I recorded, in my journal entries, the strong conviction that the young are already scientists.

I expressed the view that science is an instinctive process, innate, natural and life-long; the same view that interviewee Beatrice (a pseudomym) so eloquently expressed as, “the habits of mind”.

Continental Drift Theory and Tectonic Theory were chosen to focus the questions because of the students’ limited exposure to these ideas prior to commencing grade 10 Science and also this was the most recently explored area of the subjects’ science studies to the first interviews.

Bearing in mind the students interviewed were recognised for their academic performance but, were nevertheless ‘regular students’ in the sense that they struggled with conceptualising knew scientific ideas. I selected the student subjects for their tenacity rather than their academic strength. I believed tenacity was required if the questions being asked were to be explored to any depth.

In my journal I reflected,

> *What is science to these young people?? Some people cope better with formal science than others. Why do they cope better with formal science than others?? Better language skills?? Rational thought processing?? This also assumes that students I assess as being good at science are indeed good at it. What is it these students do or think that makes me label them as good at science? What do other teachers think are qualities of good students?*

The following interview excerpts show that students do, as is reported by Koslowski, associate science with both process and theory.

The abbreviation S.L. is me. Pauses, and the length of the pauses, I mark with dots. I record additional vocalisations phonetically. Authors notes, added to remove the possibility of ambiguity, are in square brackets. The names of the participants are fictitious.

S.L. "…Tell me what you think science is."

Rachel "Ah uum, the discussion of, I, no, making up things, theories."

Felicity "Life, the universe and everything."

Rachel "Theories"

S.L. "Science is theories."

Rachel "Yes."

Felicity "And exploring things, finding out about why everything happens."

Rachel "Why they work."

It was clear that Felicity was of the belief that explanations were important and that Rachel had the view that conceptual knowledge held centre of attention. Both were to acknowledge a secondary view of science as knowledge of facts.

> Felicity "And also at school science, not here so much, but at other schools, science is just like, learning facts, lots and lots of facts, like, how many bones you have in your body and that kind of thing, and it's [science] more than that....."
>
> S.L. "You said at other schools, and not this, this school, in particular, how is this school different in terms of, what we, consider science is, do you think?"
>
> Rachel "You're training us to think."
>
> Felicity "Yeah, you're making us think, and things like writing essays in our science tests, like that certainly wouldn't have happened at my other school, like our tests were kind of, multiple choice, 50 questions,…..kind of, sort of thing….."
>
> S.L. "So you had to answer some facts, what is this fact, what is that fact, yeah, and you're saying that writing an essay what is that doing, instead of knowing facts, what are you showing when you're writing an essay….."
>
> Felicity "Understanding…..showing that you actually understand, like, things….."

It was interesting to note that these students thought learning science as they experienced science was more enjoyable. The students' statements supported the notion that students believe theoretical explanations because of the authority of their teachers. Another student, Beatrice, also suggested teacher authority as a significant reason for accepting tectonic theory.

> Beatrice "…..Um yeah, I reckon, I reckon it's pretty logical, like you know I've been introduced by you to all the different doubts and all the different side argument and everything and, but I still reckon that's what happened because….because that's what the big people reckon, that's what the scientists reckon…..and I reckon all their reasons seem pretty O.K."

In spite of the validation of the view that students grant authority to their teachers, the true story is more complex. Albert and Leo (paired interview) indicate that the authority of the teacher is only one of a few parameters considered by students when contemplating the acceptance or rejection of a scientific concept.

> S.L. " You talked about before, about proving ideas and that's what you felt science was, was to try and go out and prove your ideas, as best you could, knowing that you can't prove them absolutely, but you can find lots of evidence to support them, and you see the conclusion part as, demonstrating that proof."
>
> Albert "Yep."
>
> S.L. "Is that pretty much what you're saying?"
>
> Leo "Yeah."
>
> S.L. Alright, um, question 11 says, what does it mean to reason, and I think A. you said something about that before. What does it mean to reason?"
>
> Albert "…..Mmm…..you've gotta make sense of something. Reasoning…..mmm…..you have…."
>
> S.L. "Because criterion 4 talks about reasoned conclusions, as opposed to just conclusions.
>
> Albert "You've gotta gather up evidence and use them…..to…..um…..to find your conclusions, because that way you've actually got a logical reason to think what you think, whereas if you just go out and pluck something out of the air and say yes it did or no it didn't it's because of this and you have

no evidence to support it then, you're really not doing science you're just , making up a fairytale ha ha, I don't know just making stuff up."

S.L. "And science isn't made up?"

Albert "Well, it sort of is because…"

S.L. "Well before the statement talked about intuitive leaps into the unknown, you know, that's kind of making stuff up really, isn't it?"

Albert "Yes, but….I don't know, to get a conclusion you have to have…..some evidence, or you have got a conclusion, really you've gotta gather the evidence and um, have reasons, like, whether you have two people arguing about it…..two different things, that could've happened and…..or two people arguing about why something happened……there still they can, still be both reasonable but…..I think I am confusing myself."

S.L. "No I think you're right, it's about logic is what you said, you know you have to have some logical reason, you know reasoning is about logic, you know formal logic in there somewhere."

Albert "You have to have reasons, why things happen, to say something happens."

S.L. "Yeah but I might make a reason up as well, you know I might say that, you know."

Leo "Yeah and you'd probably go out and try and prove that right as well."

Albert "You'd probably need to have evidence for your reasoning, so, you have to do your experiments and get all the reasons together and then sort of figure out which ones fit, and which ones don't…..and then you can use them to …..try and prove ideas……"

It is clear from the conversation that the students accept the primacy of evidence in the acceptance or rejection of ideas they consider. My authority as their teacher reduces as their understanding of the relationship between theory and evidence increases.

Beatrice, who I interviewed alone, indicates that not only does authority drive belief in scientific concepts but also the cogency of the gathered evidence provides motive force.

S.L. "Tell me what you think science is?"

> Beatrice "…..oh no way ha ha ha oh um….I don't know, the study of the world and all living things and everything….but not like English language because that's what English is but of like how things came about and how they've developed and what's behind it all kind of thing."
>
> S.L. "Do you think that thinking in science is similar or different to other subjects that you do, and how is it similar or different?"
>
> Beatrice "I reckon it's a different…..thinking in science….because in any other subject I've never really had to think about it that really happened or is that true or you never really have to think about why things happen or if the actual theories are true you just like in English you don't really do anything like you just do languages and writing and you know….ha."
>
> S.L. "I understand what you're saying um so you think that in science it's asking you questions about why you should believe something rather than another thing whereas in other subjects you just take everything for granted more or less."
>
> Beatrice "Yeah. And with science there is different ways you can go kind of thing and there's more…"
>
> S.L. "So science is open to interpretations. You would agree?"
>
> Beatrice "Yep!"
>
> S.L. "But isn't art open to interpretation?"
>
> Beatrice "Yeah…..But…..it's not the same. A model of something is not the same as a theory…..that's a couple of thousand years old…."
>
> S.L. "OK uum this one kind of links to the second the second one here. How do you go about deciding whether or not a scientific idea is believable or not…you know an idea such as plate tectonics or natural selection or whatever you care to think of in terms of science. How do you decide whether or not you choose to believe it what do you go about doing?"
>
> Beatrice "You've gotta research it and find out all you know about it and then just work out what…..why everyone thinks it is believable. You could ask people about that why they think it's believable and arguments they have and then other people about why it's not believable and if you read some papers on that and then see which arguments are more logical and which ones are more believable…."

Clearly, the authority of others guides Beatrice's conception of science but she grants that authority under licence. The arguments for and against are being analysed by this student with the outcome being contingent upon the strength of the arguments proffered. When questioned about the possibility of very young children being able to reason Beatrice responded as follows:

> Beatrice "I think, I think kids that are about 7 up to 12 or something I reckon they can reason I mean they can't go as extensively as we can reason but they can still reason like you know I can reason like I don't know…..I don't know whether stealing extra dinner or extra dessert would be a good idea and then no it wouldn't because I'd get found out and I wouldn't have any more dessert for the rest of the week they can still reason."
>
> S.L. "I would agree with you and in fact I think um Barbara Koslowski…the research[er]…has done stuff on that and she thinks kids as young as 4 or 5 can actually um reason really well just that we don't understand how they're doing it. So it's about us understanding how they're doing it."
>
> Beatrice "I reckon it's instinctive"
>
> S.L. "You think it is an instinctive process?"
>
> Beatrice "Or something yeah."
>
> S.L. "It's a good observation."
>
> Beatrice "Well as long as I can remember I've always been able to reason kind of thing just being able to go no don't do that because I'll get into trouble or something."
>
> S.L. "So you can't remember a time when you didn't reason so you think when you became conscious of your own mind that was when you started to reason?"
>
> Beatrice "Probably ha ha well I've got a pretty bad memory so…."
>
> S.L. "My son's 15 months old. Do you think he's reasoning at the moment do you think he's working out?"
>
> Beatrice "I don't know maybe a bit or something….."
>
> S.L. "Because I know that if he wants some food he'll climb into his high chair and sit down and bang on top of it because he's hungry and he'll do that so he's kind of worked out that the high-chair somehow means food."
>
> Beatrice "Ha ha"
>
> S.L. "I think he understands cause and effect as well so I think that it's just the way we don't understand how it works at the moment."
>
> S.L. "This is another more difficult question I think, what does it mean to reason……what do we talk about when we say that people are reasoning

that out or they're drawing a reasoned conclusion rather than just a conclusion I could say for example dead people have eaten carrots and therefore carrots cause you to die you know that would be someone drawing a conclusion but is it reasoned?"

Beatrice "No."

S.L. "So what's the difference between a conclusion and a reasoned conclusion?"

Beatrice "Oh logical reasoned is logical it's kind of like logical…..you know logical really…."

S.L. "Yeah"

Beatrice "So if you draw a reasoned conclusion then you've kind of looked at the logic in it and if it could happen and looked at the different arguments kind of thing on both sides and that's reasoned you've reasoned yourself out kind of thing but if you just draw it and yeah that's right and you don't look into it any more then it's unreasoned."

S.L. "What or how do you think students should be taught in order to teach them to reason scientifically?"

Beatrice "How should students be taught so they can reason?"

S.L. "Or what do you think we should teach students to enable them to reason scientifically?"

Beatrice "Well I think you've taught me a fair bit about reasoning kind of thing just by all the stuff that you did in the geology unit about…..especially that bit where you had to get all the…I don't know just the things like activities like all the for and against arguments for a theory and then making students weigh it all up to see if it would be logical or which, which arguments hold the most kind of strength."

S.L. "Yeah what I've tried to do is I think in this particular case with geology I tried to tell you a story that I myself don't believe I try to get people, encourage people to think about the expanding earth model as an alternative to the theory that's known by everybody which is plate tectonics to try and get you to disbelieve the plate tectonic theory and believe another one but I didn't get any converts no one believed the expanding earth model so there was something about the plate tectonics that one in fact I consciously told everybody about the problems that I saw in it that you know really is there enough force behind ah those convection currents in the mantle to drive those big plates around or is it?"

Beatrice "Well, by the time you're in grade 10 you don't really care what you [referring to me] say you just do what you think kind of thing."

S.L. “ So, you don’t”

Beatrice “So, I don’t think you well you do but I don’t think you have as big an impact as you would’ve in grade 7 or something because in grade 7 you just believe what your teacher say coz they’re right but in.”

S.L. “When does that stop?”

Beatrice “I don’t know ….gradually.”

S.L. “It gradually stops you didn’t find that there is a…..”

Beatrice “No, it gradually kind of went on for in grade 9 and the I think…..kind of when I went to my Christian School I was just like not listening to these teachers they don’t know what they’re talking about.”

S.L. “So, how old were you when you went there?”

Beatrice “Um I was through the middle of grade 8 I think…..slowly slowly it came like near the end of grade 8 I just started thinking no way……kind of thing.”

S.L. “So, when teachers told you stuff you kind of listened but didn’t necessarily believe?”

Beatrice “I listened and kind of weighed it up kind of thought yeah uh huh.”

All students made suggestions of the difficulties in transitioning from a naïve to a sophisticated conception of science. The students Albert and Leo had difficulties in accepting the absence of ‘science as truth’, nevertheless they both realised that their own transformation was a requisite of an obligatory maturation.

S.L. “What or how do you think students should be taught, in order to teach them to reason scientifically…..so that’s the what or the how….”

Albert “…..To teach them what, to teach them how to.”

S.L. “How to reason scientifically, because this is basically the aim of science isn’t it, we want people to come out, being able to think like a scientist and to do that, is to reason scientifically, now how do we, how do we teach students like yourselves to do that, do you think you can do that now, whereas you couldn’t before you know, have we taught you how to do that, do you think, that might be a way into the question?”

Albert “Yeah, I think it’s, helping the person, like a student out with the ideas like say, like in grade 9 you say this, it. What we’re researching this is, how you do it, and then you make them think.”

Leo “Yeah you have to.”

Albert “Like just give them.”

Albert & Leo “a general idea.”

Leo “Yeah.”

Albert “Yeah a general idea of what you have to do”

Leo “But then you have to leave some of it unanswered for them to find out for themselves. Mmmm I think that’s where they get really crabby because they need to know the answer and that.”

Albert “Oh yeah, I used to get really crabby because I just was a big….I needed to know the answers I needed to know why stuff worked, I just didn’t understand it and then I’d get all confused and stuff but…..in the long run I think it helped because….ah…..it makes you think for yourself and you know you start to understand.”

Leo “You start to understand.”

Albert “Otherwise you just take things for granted and then you just think, oh well, he, they said it worked, so it must work, whereas it might not, they might’ve just been…..you know, that could’ve be just what they thought, so unless you actually doubt it yourself, then you’re never gonna find out for yourself, what it really is.”

S.L. “So you think, you both think the way that you were taught at this school was actually good for you in terms of reasoning scientifically, that it worked, that you feel more confident about it, being able to do that now and what, what is it that you think we did then, you know, the what and the how what is it we did and how we do those things that you thought was good, and what maybe, were the things that were bad in your mind in terms of those things, you, you’re saying E. that the good things were, we made you think, you know we gave you some of the ideas, but not all of them, and made you think about the rest and you were saying some of those people, that didn’t like that were people who just didn’t want to think for themselves and that was creating difficulties.”

Leo “And they just wanted straight answers, and to be taught and not learn for yourself.”

S.L. “What is it, we did we do, do you think that, helped in that?”

Albert "You made us think, we didn't really have any other choice because."

Leo "I think like, what we said before was that…..we got, you gave us the basics, the basic idea….of how to do things and then…..we, we went off by ourselves or in groups, and worked why it happened and why things….do what they do."

Albert Mmmm, so we're given a base idea and then we had to go and…"

Leo "Research"

Albert "Research and find the rest of the answers for ourselves and….things were thrown in to confuse us, you go, maybe it does and maybe it doesn't, or why does it do this and why does it do that, and heaps of questions that we probably couldn't answer ourselves but."

S.L. "It's interesting in hearing your opinions because I know that you had a…a difficulty with the way that I was teaching things and that you requested a transfer, which I thought was good that you were assertive to do that, do you, do you now think that, that decision was wise, do you think that you probably weren't ready for the way that I was doing things, maybe, but now you could be perhaps, and things have changed for you somehow?"

Albert "I think that changing classes for me was a good idea because….I understand Mr B.'s way of teaching like really well….I don't know why I think it's just, cause…..like mmm….you both teach really differently, and last year I actually……understood how you taught, and then I think, its like, I don't know whether it was this, like the whole year or whether it was just physics and I was just really…..confused ha ha and didn't know what was going on, I just couldn't understand a thing that was going on so."

S.L. "Yeah."

Albert "That's why I changed classes, and yeah, I think it was a good idea for me, because, in the end I actually ended up understanding what was going on."

S.L. "And enjoying yourself to, yeah to boot."

Albert "Yep."

S.L. "That's good, what is it that you think is the subtle difference between, us as teachers, in terms of the way the we do things, what is it that you think that, maybe I was doing, that you didn't appreciate, didn't like or wasn't good for you, what was things that Mr B. was doing that were good for you and worked."

Albert "Well….."

S.L. “How was it…the difference?”

Albert “Mr B. was probably more of a factual teacher…..um…..and you asked more questions ha ha like um…..with Mr B., if I asked for something, it was just explained and…..”

S.L. “So you hated the fact that I never gave you the answers to questions?”

Albert “Ha ha ha yeah! I was just like, I didn’t know what was going on and oh well maybe this and maybe that but, what! Ha ha.”

S.L. “I think in my mind that’s the way science is, and it’s all full of maybes, there isn’t anything that’s absolute and that’s the problem, that most people face.”

Albert “Well, I just think, it just confuses me more because then I don’t know whether….you know.”

S.L. “Yeah.”

Albert “Like science is very maths based as well, because of all the formulas and stuff you use, but even when we’re doing physics I couldn’t understand what was going on in physics, even though I was using formulas because…….. I don’t know, there were so many whys and maybes and ifs.”

S.L. “Yeah. Now I know L. you, you had times during the year where things got really difficult for you and you know, it was quite emotional, you know, traumatic even, I could describe it.”

Leo “Ha ha ha ha ….ha”

S.L. “But at the end, having come through it, you think the trauma may have contributed to your development, do you think that emotional upheaval was actually of benefit to you in the end, that the stress led to something that was positive.”

Leo “Like you said before if you…..if something, if you research something, and it really annoys you, but you eventually…..understand it in the end, you will remember it for a long time because you went through all that emotional state ha ha.”

S.L. “Yeah.”

Leo “And um, you remember that because I remember…..I had to come and confront you and I was pretty emotional and then, I well, I remember that because….of what I learnt….if you know what I mean?”

S.L. “Uhha”

Leo “Do you get what I mean Albert.?”

> Albert “I had big problems….with…..I don’t know I really get stressed out, really easy which is probably why I left [my old school] and stuff in the first place….and then I…..it was the same this year with lots of ….work and stuff but…..”
>
> Leo “You remember what you learnt.”
>
> Albert “Yeah you remember what you learnt.”
>
> Leo “You went through it all and it was really hard.”
>
> Albert “I remember I used to talk to Mr B. about it lots and the stuff that he taught me about ….like myself or…..basically life’s little wonders, will, I don’t know stay with me because….they got me through it.”
>
> S.L. “You can see yourself from the outside, maybe for the first time even?”
>
> Leo “There were times when, um, it was a bit traumatic and I was going to change classes like Albert, but I didn’t and I’m glad I didn’t in the end because I was going to change classes, because I knew that I wasn’t doing science in year 11 and 12 and I wanted to get the best marks possible and I didn’t think that I could get that, being in your class….whereas now, I know I can get the best marks I can and I have learnt heaps, because I, a real lot.”
>
> Albert “I’m doing three sciences next year….and I don’t really know why I just sort of went…..they just sounded interesting.”

The students interviewed simultaneously seemed to respond to each other’s comments and my involvement was minimised, moving the discussion from one point to the next. The technique of using paired interviewees offers, I believe, great possibility for extending understanding within the discipline, currently clouded by interviewer language. Here the students demonstrate the value of conversation with a significant other.

> Rachel “Yeah, I don’t know, mum was talking in, in Malaysia that they have like, a really big emphasis on like, ah, exams, and stuff even like when ah, like kids are in kinder they do exams and that kind of stuff so I suppose that would be very strict and disciplined and they would be taught facts instead of taught, being taught to like think, and use their creativity but, then I mean I’m assuming stuff here so.”
>
> S.L. “No I, think um, it’s an interesting observation do you think that, what you’re doing…is better…than in the other suggestion?”
>
> Felicity “It’s more…..enjoyable.”

Rachel “Yes, I’d have to go along with the enjoyment and if you enjoy something you do it better, so…..”

Felicity “And you’ll learn more, and also like, if you just sit down and learn every single bone in the body, you’ll forget it, whereas if you really understand something then you’re not likely to forget it…..which is why Mr G. is always going on about having to understand the basis of maths.”

S.L. “Yeah, so,…..if you, if you’re doing that, what is it that you have to do so that you really understand it, what is that you’re doing differently to learning a whole series of facts, which you say you would probably forget in a month’s time.”

Rachel “Proving it to yourself.”

Felicity “And talking to people about it, we do lots of that.”

Rachel “Talking, yes.”

S.L. “The talking’s critical.”

Felicity “Yeah, and I suppose you could do up experiments and things like that but I.”

Rachel “We’re really not into that ha ha.”

Felicity and Rachel had acknowledged the following as attributes of science:

1. Science is knowledge of facts.
2. Science is knowledge of concepts.
3. Science is understanding concepts.
4. Science is the process of exploration of explanations of phenomena.

What was it that engendered these students to accept evidence of a particular phenomenon or concept in science? I had asked, what was the difference between good and bad evidence? According to Beatrice one must guard against simply accepting things as true as some sort of habit. Beatrice intuited the value of the evidence and strategically accepted some evidence and alluded to accepting the views of significant others.

S.L. “…How do you know the difference between good and bad evidence?”

Beatrice “It’s reasoned good…ah bad evidence…..oh I don’t know.”

S.L. "say like an observation we take some recordings how do you know what's good and what's not good in terms of the evidence you are trying to weigh up because you're saying constantly through this interview that you're weighing things up and deciding whether or not something's worth supporting or not so therefore you're having to make those decisions about what's good and what's bad in terms of the evidence."

Beatrice "Yeah"

S.L. "How do you go about doing that……deciding whether or not to believe something"

Beatrice "just…oh I don't know……it's just……it just happens ha ha"

S.L. "You kind of have a…"

Beatrice "instinctive…..no feeling"

S.L "So you instinctively go no it's not believable and…"

Beatrice "And then yeah…..most of the time and then think about it after that kind of thing yeah."

S.L. "You see some common sense ideas aren't true like ah let me see for example in physics people often think that you need a force to keep an object moving whereas Newton's first law of motion talks about objects having inertia that if an object's moving it will continue to move in a straight line unless a force acts on it, and that being, friction on earth tends to slow things down and stop them so on earth people tend to think that if a force isn't applied it won't keep moving."

Beatrice "yeah"

S.L. "So that one's a counter-intuitive kind of statement so how do you guard against those kind of ideas that are wrong that are kind of common sense views."

Beatrice "Of having spent your whole life with people saying this is what happens and then you have to get into another habit of having to question everything and saying well that might not be right and then thinking about why it might not be and if the reason for why it might not be aren't very good then obviously it is."

Here Beatrice's failed attempt at refuting an hypothesis leads to the corroboration of the hypothesis. The hypothesis is strengthened by the failed attempt at refutation.

S.L. “So that habit of questioning everything that’s one of the things I get criticised for as a teacher by students I think you’ve been one of the people who’ve criticised me for questioning everything.”

Beatrice “Yeah well…..oh I don’t know I say you accept the really obvious things…..and you shouldn’t question everything it just gets boring then you’ve got no time to do anything else.”

In the case of Albert and Leo the evidence is valued as good if it is logically consistent with previous knowledge and gathered information.

S.L. “How do you know the difference between good and bad evidence…..”

Leo “What do you mean by good and bad evidence?”

S.L. “Well in the traditional sense of the word good and the traditional sense of the word bad and you think of evidence as being any observation, really, how do you know that an observation made by somebody is actually a good observation, versus one that’s a bad observation?”

Leo “Because they’ve researched it…..and…..if they researched the topic and…..they’ve come out with….a good….theory, for an observation then…..it’s good, but if they’ve just kind of, if they haven’t looked at, deeply into it and they’ve just said, ah, that’ll do then it’s a bad one.

S.L. “You were talking before about um, conclusions and things that…..uum…...some things are believable, you just go yep, believe that and then you go some things…..nah and that’s I think, a way of sort of recognising the goodness an badness in them….What is it that makes you reject something out of hand, when somebody says I’ve collected all this information, let’s use, oh, I don’t know, overhead power cables causing cancer in children, now do you, is that something that you would be willing to believe, uum, do you accept the evidence that’s there, do you reject the evidence that’s there, that’s there, ah this is an example, you could use any example you like, how is it that you make a decision whether or not you want to believe something and it’s based on the sort of goodness or badness of the ideas I think.”

Albert “It’s gotta be logical.”

S.L. “Logical….., so good is logical, bad is illogical?”

Albert “Yes, the stuff you’ve been taught…..like um.”

S.L. “Knowledge based?”

Albert “Yeah, knowledge based, just as a…..”

S.L. “Knowledge based is good and without knowledge, it’s bad yeah?”

Albert "Yeah."

S.L. "Anything else?"

Leo "I think it depends…..on, whether it's good or bad, it depends, it depends on the person, like Albert could think one evidence is bad and I could think it's good, it depends on what you believe."

Albert "It depends on how you perceive things,……mmm, on how you perceive evidence….mmm. Like two people can look at the same set of results or evidence and draw different conclusions from it."

Leo "Like some, like some example, someone could look, like Albert and I could look at a picture on the wall and he can say geez that's beautiful and I could say, no it's ugly, it's bad, it depends on what you see."

What was the role of experiments in science? How do students consider the purpose of experimentation? Experiments were designed "to prove things to yourself" and also to "find out the truth". The way in which students decide the value of evidence also, once again, invokes the concept of intuited (common sense) understanding.

S.L. "One of my students that I teach in grade 9 was critical of the fact that he'd got to this late stage in science in grade 9 and he thought that he wasn't doing any experiments anymore and that you know, there was something bad about that, that he was avoiding doing experiments and that the science, therefore was bad for the reason, what do you think of his opinion?"

Felicity "Hey, I'm all for not doing experiments, but you need to do them to…..like you have to have some proof, you can't just think things."

Rachel "Or base everything anything on like, what someone says."

S.L. "So why do we do experiments?"

Rachel "…..To fill in time in science…..um, to prove things to yourself."

S.L. "To prove things, yeah?"

Felicity "Yeah."

Rachel "Or like, ah, um the whole,…..I don't know, will a flame burn, in like carbon dioxide and like you'd put like, you'd gather some carbon dioxide from, you know, put in some, like something in some acid, right and then you hold the flame underneath and it'll go out, so instead of just, like, accepting it."

Felicity “Accepting it.”

Rachel “Like actually having it there and like proving it to yourself, like it might just.”

S.L. “So you’re learning it through concrete examination of it.”

Felicity “Like you can really believe it if you’ve actually seen it happen.”

S.L. “Yep, so you do experiments to reinforce the ideas that you’ve got in science, um, some people say that you do experiments also to…prove ideas incorrect, you know, if you really want to test your idea, you do an experiment you set up deliberately, if it works, would prove that your idea is in fact incorrect.”

Felicity “Mmm, yeah.”

S.L. “So that’s another possible reason. And when you said before that you do experiments to prove ideas correct.”

Felicity “Yeah…..”

S.L. “But not to prove them incorrect.”

Felicity “Mmm, well you can do it both I suppose, like there is some people who must, who go around trying to prove that some ideas are not true.”

S.L. “What’s their motivation do you think?”

Rachel “Ah, money, perhaps, and just like wanting to figure out things.”

Felicity “Also to do like, hey, we’ve been right for the last, thousand years, and we’ve been wrong kind of thing.”

Rachel “Or, to find out the truth so you can like just,…..we can go further…..”

S.L. “Yeah, so if you’ve been misled by an idea and you prove it incorrect then that’s, that’s a good thing, it’s not a bad thing.”

Felicity “Yeah.”

Rachel “Yeah.”

S.L. “Alright let’s ah, let’s move on to question, question 7. How do you go about deciding whether or not a scientific idea is believable or not….an idea such as plate tectonic theory or natural selection?”

Rachel “Whether it sounds believable.”

S.L. “It sounds believable, what do you mean by something that sounds believable, what is it about it, that convinces you?”

Rachel “Well it’s, I suppose you get like, other facts, I suppose like um, you’ve got the rules of gravity and…the law of gravity and, and other stuff, so if someone said that um,…..They were going to fly up in the air, right because of the law of gravity, you’re gonna say nah, they’re either lying or they’ve got some help or they’re a fake or something like that, so whether it sounds bad or not, it’s like, you just relate it to what other bits of information you know and just like, kind of deduce it, I suppose.

S.L. “Yep, so it, it has some sort of essence of truth to you, that you think yep, that sounds true, and sometimes your ideas that are, they sound true, are in fact, not true, aren’t they, you know, if we use Newton’s First Law of motion says that an object keeps moving in a straight line unless a force acts on them, but if you ask most people, do you require a force to keep an object moving most of them say yes, because on earth, friction gets in the way, most of the time and things don’t they, you know, stop by themselves, sometimes your intuitive answer, your kind of gut reaction, that says that it’s true, is in fact wrong, you know, how, do you then guard against that, to know that you’re not just believing something that seems to be true but in fact it’s not, how do you guard against, accepting ideas that are in fact wrong?”

Rachel “……Um……”

Felicity “I suppose you have to, kind of, you have to explore it for yourself and you have to question things, you can’t just accept it’s true and by talking to people that you trust and respect their opinion, that could like, if someone, like if you for example told me, I don’t know, you’d seen a Tasmanian Tiger, if anyone else said that, I probably wouldn’t believe them, but I know that you’re a fairly, sort of straight kind of guy and you, you don’t make stuff up so I would believe you.

S.L. “So some people are more believable than others based on their reputation that’s been developed, how do you develop a reputation like that, what have I done, that’s made you believe me when I say things versus somebody that you wouldn’t believe?”

Rachel “How about you’ve never done anything or said anything that……makes us question your reputation.”

S.L. “Yeah, OK, yeah I accept that…..um, the…the question again was, you know how you decide when something is believable or not, so…..you believe it based on the reputation of the individuals telling you, why do you reject something, other than, you know, because their reputation isn’t solid, why would you reject an idea that somebody is telling you?”

Felicity “Because it sounds completely ridiculous…..”

Rachel “Because they don’t have enough evidence to back it up.”

S.L. “Yeah, so an idea like the expanding earth model for, um…..to explain continental drift that’s the model of, ah, Carey, The Tasmanian Professor of Geology, he said that the earth used to have a radius of about half of the size it has now and it’s expanded to the size and it’s cracked the crust and spread all the continents that way they are now and then you’ve got a very thin oceanic crust underneath where the, the molten, ah, mantle has, set and, because of it being pulled apart, you know what is it about that theory that you don’t believe versus the one about plate tectonics explaining the continents drifting around, you know one is more believable than others, what is it about those two ideas that, make one more believable?”

Felicity “The part that earth has doubled in size sounds ridiculous……because it’s, it would stuff up all the orbits and things like that, wouldn’t it?”

These two students are logically rejecting ideas they find implausible. They see the role of science is to discover the truth and that the truth can be known.

S.L. “So science is a way of doing, a way of knowing, a way of understanding stuff, as a process...?”

Felicity “Mmmm, yeah I suppose…..”

S.L. “Alright the second part says that it involves the falsification of existing theories…well?”

Rachel “That’s true too.”

S.L. “Proving ideas wrong…you know in the past there’s been these ideas that they’ve proved wrong, the earth in not flat, the earth isn’t at the centre of the universe etc., yep, intuitive leaps into the unknown…like guessing.

Felicity “Intuitive leaps into the unknown.”

Rachel “Most people can do that and they they.”

Felicity “You can, you can leap into the unknown but usually once you’ve got there, you go back and you look at like, how you got and whether or not it’s believable.”

Rachel “Yeah, and find evidence, to like support it.”

S.L. “Yeah well Wegener was the guy who intuitively leaped into continental drift, didn’t he, and he was rejected and even after he’d died in 1930, um it wasn’t until the late 60’s that people started accepting his views, so he intuitively leaped into the unknown based on some observations that he’d made as a meteorologist and ah, an explorer, um and…the last one, beauty in new theories and aesthetic completeness, do you think that science can be beautiful?"

S.L. "Alright do you think that science involves rational thought…as opposed to irrational thought?"

Felicity & Rachel "Yes."

S.L. "So it's rational, logical rational?"

Rachel "Yeah."

Felicity "Mostly."

Rachel "You'd expect it to be."

Felicity "You get a few with."

Rachel "People."

Felicity "That…..I think."

S.L. "Can you give me a for instance?"

Felicity "Yeah, I'm just thinking…..um."

Rachel "Ha ha ha."

Felicity "…Well I suppose that, your Tasmanian dude's theory about, um, the earth, doubling in size, I suppose that's rational, like with the earth expanding at a rate of 1mm, mil', or whatever it was…but then, oh I dunno…he must have…..kind of, irrationally thought…like why it was and he just wanted to explain it, which is why, he came up with that theory."

S.L. "That's an interesting idea that you irrationally think of an idea first, that's like the intuitive leap that you know."

Felicity "Yeah."

S.L. "You *irrationally* think of it and then you go and test that idea, to try to make it *rational*."

Felicity "Like Rachel. was saying in art they they're supposed to show the process they came to, to get a piece of artwork and she says she just does it and then she goes back and explains it later."

S.L. "OK, yeah…alight let's go on to question 11, what does it mean to reason? Because the, the criterion 4 says reasoned conclusions, so as opposed to conclusions."

Rachel “To think.”

Felicity “To reason.”

S.L. “Because it says reasoned conclusions, it doesn’t say, just draw conclusions, it says draw reasoned conclusions, so what does it mean to reason?”

Felicity “To look at everything, you’ve got all the information and think well that’s like that and that’s like that so you come to kind of a logical sort of decision on what’s what.”

S.L. “And how do you demonstrate that logic to your, your supervisor, the person who’s, reading your work that you’ve generated?”

Rachel “You write down your thoughts, like how you got to where you did.”

Felicity “And you show them, the evidence that kind of, relates to it… like in maths when you have to…you get given a question and you have to show your working, to get to the answer and you won’t get good marks if you don’t actually show the working you just have the question and the answer because you could’ve copied that, from anywhere, but if you show the logical steps to get to your answer…then it’s, you’ve learnt more and you’ve understood more and it could be the same in science.”

S.L. “So, a step-wise logic, so this, then that, then that, then that, leads to this, this final conclusion yeah.”

Felicity “Yeah, with it like, your steps being reasoned, and reasonable.”

S.L. “With evidence, I assume to, to support each of the basic points that you’re making in it yeah.”

Felicity “Yeah.”

S.L. “OK, um, what or how do you think students should be taught in order to teach them to reason scientifically?”

Felicity “How do you teach someone to reason.”

S.L. “Well you could ask yourself the question, am I learning it, you know, am I doing that better than I have done in the past, what is it that I’m experiencing that is allowing me to, to make those changes, you yourself said that you were getting better at it, that you thought that you were better at it now than you were in grade 8, and maybe the experiences that you’ve had have led you to develop those, ah, skills, so what is it that you’ve experienced do you think?”

Felicity “Well the teachers you have…

S.L. “What about them in particular, do you think?”

Felicity “Well they let you ramble on forever and like kind of, sort of, I don’t know…..talk about stuff…..”

Rachel Um…..I think…..making you think ha.”

S.L. “And how do we do that, how does somebody make you think about something?”

Felicity “By asking you tricky questions.”

Rachel “By not telling us yes, by asking us questions and not actually giving us ah, a straight forward answer you just like, leading them to a conclusion by asking questions and letting them get there by themselves.”

S.L. “Yeah.”

Rachel “Sort of.”

S.L. “OK so, leading you along the path, but not actually giving you the answers to things is what the teacher…..”

Rachel “Yeah, kind of like Mr G. does in maths, like instead of just giving us the, damn formula, ha ha ha he’ll like, makes us sit there and like, um.”

Felicity “Spend like ages working out.”

Rachel “Yes and like, see the relationships between like, two different things and I just think, like, think about it and…..do stuff, I don’t know.”

S.L. Yeah…um…so, you know you’re talking about conversations, you’ve had lots of conversations with people about ah, your science and you think that’s contributed greatly towards your development of your thinking skills because people are, is it just because they are listening to what you’re saying or is there a kind of two-way dialogue going on.”

Felicity “Yeah, they’re listening and also they give you bits, like they ask you questions, not like, like questions, questions, but they sort of ask you things that make you think, well, that’s quite an interesting thought, I wonder if it’s true or…”

Rachel “Prompt questions.”

Felicity “Yeah.”

S.L. “How do you know the difference between good and bad evidence?”

Rachel “How do you know the difference?”

Felicity “I don’t know, can you?”

S.L. “Well I’ll give you an example that…that might help illustrate a point, um, ah, Professor Carey’s idea of an expanding earth….um, is essentially rejected by the scientific community and he has evidence that supports that, plate tectonics is a theory that’s generally supported by the wider community as well as the scientific community and there’s evidence to support that as well…..people are saying, well, this is a good theory and that is a bad theory, and they’re deciding therefore that this evidence that’s good and that’s bad evidence, what is it, do you think that makes you, want to believe a particular piece of evidence, a particular observation, as opposed to something that’s bad?”

Rachel “It matches what you believe.”

Felicity “Yeah.”

S.L. “So it matches in with your own beliefs’ pre-existing ideas?”

Felicity “And with what the people you respect say, so if Andrew told me that, um…..that dude was right, the Tasmanian one.”

Rachel “You wouldn’t want to go along with it.”

Felicity “I wouldn’t be likely to believe him, but if Mr B. told me that it was true, then I’d be much more likely to.”

S.L. “Well how do you guard against becoming a clone of people you respect therefore, you know, how do you think for yourself, rather than thinking what other people are thinking because you’re telling me that if I tell you stuff you believe it, accept it, because I am believable.”

Rachel “Um, no.”

Felicity “Not straight away.”

Rachel “It would just help, like, it would probably, if you told me something was correct.”

Felicity “It would influence you.”

Rachel “Yes, so you would go out and explore it whereas if, like Andrew told me something was true, well then it’s like, O.K. whatever, and just like, forget about it.”

Felicity “Dismiss it and yeah, whereas if you and Mr B. said, well this guy’s theory is true, then I’d be more likely to think about it, and sort of.”

Rachel “Explore the issue…..and find evidence and.”

S.L. “So, you would reject people like, like Andrew, if we mention anyone in particular and you reject them, and you don’t think they have anything to offer you, in terms of your own thinking.”

Rachel “Um, no, not exactly…..but, it doesn’t exactly help….ha ha that it’s him.”

S.L. “So when you say, not exactly reject it out of hand, you don’t think that there is possibility.”

Felicity “It won’t have a big influence on my thinking.”

Rachel “Yeah.”

S.L. “So there’s a scale, some people have a high influence and some people have a low influence and the people that you um, what is it about Mr B. and myself that you think…..are?”

Rachel “You’re adults, you’re teachers, you treat us sort of as…..like…..equals, sort of, um…..you…..know stuff, or at least you.”

Felicity “You’ve been around for longer than us.”

Rachel “Yes, exactly, um…..you act as if you know stuff.”

S.L. “So like a confidence thing, you’re talking about?”

Rachel “Ah, sort of, yes….um…..I don’t know you probably got a certificate, somewhere up on the wall saying you do know stuff…..you’ve never done anything that makes us think you don’t know stuff, um…..ha ha ha.”

Felicity “And we trust you.”

S.L. “Trust?”

Felicity “Yeah.”

S.L. “And we haven’t broken the trust so therefore we continue to.”

Felicity “No.”

S.L. “We continue to.”

Felicity “We have no reason to doubt what you say.”

Much of what the students referred to was about the probabilistic certainty of theirs and other people’s knowledge claims. Scientific truthfulness and probabilistic certainty entwine.

Chapter 9 – The Left-handed Frog

The left-handed frog is an idea of Richard Feynman (1998) representing the consequence of optical isomers in biological systems being of the 'L' or left-handed type. What do left-handed frogs eat? The digestive system of the frog cannot process chemicals that are of the wrong or right-handed, optical isomer. The answer necessitated is left-handed flies. When we normally consider the food of a frog we avoid these unnecessary complications.

Werner Heisenberg (Heisenberg, 1999) showed us the capacity of people to measure was not limitless. Max Planck's constant had defined the critical limit to which location and momentum could be measured. Planck's constant ($\hbar = 6.626 \times 10^{-34}$ Js) represents the smallest piece of energy possessed by a photon of light. Kurt Gödel (Cyphert, 1998) had proved that there were things that could not be proved. Hermann Weyl had claimed that no real contradictions to the facts exist. The consistency of nature is taken as a fundamental principle and therefore the inference that there are no true paradoxes in nature. Certainly they do exist in logic, but that is a construct of man.

I was flailing around in search of paradoxes within nature. Travel into the quantum world seemed unavoidable. Quantum mechanics (QM) provides a rich vein of paradoxes to tap; however, I found the quantum world's difficulties insurmountable. Richard Feynman (1998) was correct in that regard.

I carried out my conversations, for the most part, with authors rather than embodied people; no-one I knew could fold their minds to include anything other than a vague notion of QM. The people I knew certainly knew nothing of uncertainties. Eventually I found Sanders Bais's (2005) beautifully written book *The Equations – Icons of Knowledge* that brought me as close as I would ever come to claim I knew anything of QM.

Schrödinger's Cat – a thought experiment

Based on the Copenhagen interpretation of QM, wave functions collapse generating specific certainties rather than indeterminate probabilities (Cf. Silver, 1998) and it was the Copenhagen interpretation that led Erwin Schrödinger to create a thought experiment that is referred to as, 'Schrödinger's Cat'. A cat to inspire my struggle with paradox brought to life in the story of conversations with Charles (Cf. Chapter 7). Schrödinger's cat, concealed within an impenetrable box, with a vial of poison and a radioactive particle. If radiation from the decaying atom strikes the vial it releases the poison. The radioactive atom has a 50% chance of decaying and therefore Schrödinger's Cat has a 50:50 chance of losing at least one of its nine lives.

I was so confused I felt like Schrödinger's box concealed me.

I was pondering an academic adventure and kept coming back to Schrödinger's Cat. My introduction, in under-graduate physics, to Schrödinger's Cat had enthused me enough to read John Gribbin's (1984) *In Search of Schrödinger's Cat* and the cat had kept me entranced. Although I confess now I hadn't a clue what my lecturer was on about, there was something curious about the dual existence of this alive-dead cat.

Paradoxes of Nature

Odd examples of natural paradoxes were coming to hand, the non-integer atomic number of chlorine for example. In this case the paradox, or apparent paradox, led to the development of the concept of isotopes.

The ratio of 3:1 for the abundance of the isotopes Cl_{35} (atomic weight 35) and Cl_{37} (atomic weight 37) explained the apparent contradiction of chlorine's fractional relative atomic weight of 35.5. In this example, theory changed to account for the anomalous data and the concept of the isotope was born.

I considered the question of how life emerged creating order despite the second law of thermodynamics. I believed the terms order and disorder are subjective.

One could view what is apparently increasing complexity and therefore loss of disorder paradoxically. Deists have used the apparent increasing order as a means to confirm the existence of god because of the contravention of the thermodynamic laws. I could alternatively argue that average entropy increases in spite of localised decreases; however, this *ad hoc* modification may not be necessary if I question another premise.

It may be far better to conclude that apparently increasing diversity of life is an example of increasing entropy and not increasing order; though strictly speaking the thermodynamic laws applies only to thermodynamic processes.

Perhaps if Theodosius Dobzhansky, the father of molecular genetics, (Black, 1937; Dobzhansky, 1935) is correct, the concept of species (Cf. Wiley, 1978) is limited in its validity. I could argue that all living organisms are members of the one Dobzhansky Species and therefore the apparently increasing complexity of life is instead indicative of increasing disorder.

The species concept contains paradoxical entries such as the Wolphin. This whale/dolphin hybrid provides an example of an organism that remains reproductive after hybridisation. The Wolphin is paradoxical because a central premise of the species concept is that intra-species hybridisation produces sterile offspring. Members of the *Eucalyptus* genus are also able to hybridise producing viable, or reproductive, offspring. The D-species would make no assertions about the reproductive capacity of individuals separated by geography or the consequence of mismatched genitals.

My QM path took me toward Albert Michelson and Edward Morley's 1887 experiment (The M-M experiment). When Michelson and Morley's experiment, to measure the absolute velocity of the Earth through the hypothetical aether failed, because the experiment gave a velocity of zero, it indicated that Newtonian mechanics was insufficient. The M-M experiment was viewed paradoxically at first, until the development of Hendrik Lorentz's modification, his 'equations of transformation'; conceptualised four-dimensional space-time. (Cf. Bais, 2005)

The M-M experiment had proved the counter-intuitive observation that the speed of light was the same for all observers. George FitzGerald and Lorentz had tried to show that the constancy of the *speed of light* ‘c’ was only ‘apparent’ and not true, they considered ‘c’ appeared constant because of the measurement techniques. Later, Albert Einstein was to show that the reverse was true. The constancy of time was genuine and this entailed counter-intuitive length contraction at speeds approaching ‘c’. This sequence of events provides a beautiful illustration of the power of anomalous data in the advancement of science. What this particular example shows is that theory change started with a paradox.

Like Bertrand Russell in *The Problems of Philosophy* (1912), Karl Popper was a realist; accepting the common-sense version of a knowable external world. Like Russell and Popper I was a firm believer in realism. The science with which I had occupied myself was the search for understanding this knowable external world.

Alfred Tarski (1956) had defined what broadly constitutes truth and applied to the external world it meant, that it was possible to know its truths. Yet, it was not possible for me to know I had found the truth of the external world. Uncertainty and epistemology are coupled. The advancement of science shows us that generally we don’t know the truth, for science is constantly changing. We accept the truthfulness of our scientific claims and acknowledge that new evidence may come to light that forces revision of our theories.

The Fallibility of Confirmation

Popper’s view of science was different to his predecessors in one particular way. The verification or confirmation of theories by instances of support, for example finding a black raven confirming the hypothesis ‘All ravens are black’ or perhaps the red-shift of the electromagnetic spectrum being confirmation of the general theory of relativity, had been successful up until the twentieth century. In the twentieth century, Hempel exposed the fallibility of confirmation as a mode of operation and confirmation was usurped to some degree by Popper's principle of falsification.

Popper's (2005) examples of 'Marxism' or 'Freudianism' and Franz Mesmer's 'Animal Magnetism' or Trofim Denisovich Lysenko's 'Michurinism' had shown, according to Popper, that they were essentially immune to falsifying challenges (2005, pp. 44-48). According to Popper (op. cit.), the inability of a theory to be challenged was not an admirable quality, on the contrary Popper's view was that the more easily a scientific theory could be challenged the better the theory. General relativity was an archetype of greatness because an experiment (finding gravitational red shift) could easily falsify it. Gravitational red shift occurs because light can lose energy in a gravitational field and rather than moving slower, as the speed of light in a vacuum is constant, the light's frequency will decrease or *red shift*. By recognising this effect, Edwin Hubble discovered the expansion of the universe in 1929.

Popper declared the true test of a scientific theory was its ability to withstand rigorous challenges. To withstand falsification and to withstand attempts at locating disconfirming evidence were essential in Popper's view. Popper believed his falsification theory, as opposed to Rudolph Carnap's (1937) confirmation theory espoused in Carnap's essay *Testability and Meaning*, was not a slave to probability. Carnap's confirmation theory was a consequence of the un-testability of hypotheses such as, 'All ravens are black'. Clearly it is not possible to test all ravens and therefore what Carnap needed was a reliability test, a test that could yield only incomplete or partial verification.

Popper suggested that the conjectures of scientists, such as the 'hypothetical aether' of Lorentz and FitzGerald, are highly speculative and therefore the way to proceed was not by finding instances of confirmation but by refuting these conjectures on the basis of their logical inconsistency or the conjectures' propositions entailed consequences that were experimentally falsified.

The QM world provided yet another example of a paradox that was difficult for a novice such as I to grasp; Non-locality, or superluminal communication at a distance. Non-locality was the logically entailed consequence of the EPR Paradox. Non-locality is intuitively unacceptable hence the paradoxical nature of Einstein, Podolsky and Rosen's conjecture—their thought experiment.

I was in 'no-man's land' on the EPR Paradox but I felt it was worth making an attempt at conceptualising because of the EPR Paradox's value to philosophers as an example of a highly regarded thought experiment. Simultaneously, I was still struggling with contrasting the Barber Paradox and Russell's Set Paradox.

> *The Barber does not exist yet the set of all sets not members of themselves does exist! [if I accept the unrestricted comprehension axiom]*
>
> *Toss a coin, cut it in half leaving the bottom side down. Take the top section send it to the end of the universe. Look at neither. Then look at the bottom of the side you have. The implication is the other side is distanced and known. How is this not different to electron spin?*

I couldn't understand how my analogy with the coin was not similar to the direction of spin until I realised the direction of spin is still possibly either 'up' or 'down' prior to its observation, whereas the severed coin already has its 'spin' determined. To use quantum language, my coin had had its wave function collapsed.

> *The measurement of spin of the 'stay at home' particle impacts on the measurement of the 'travelling particle' collapsing the wave function forcing the particle to choose spin up or down. After choosing, the travelling particle is instantaneously forced into the opposite spin. Evidence shows that the two separate particles do indeed have opposite spin. Surely the measurements are real?*

Experimental instances have now confirmed non-locality's reality, but, other past experiments had also confirmed other apparently real data and it may be possible that future evidence will disconfirm non-locality.

I linked paradoxes with misconceptions through my engagement with my students. Why do my students believe utter rubbish in the face of clear evidence to the contrary, rubbish such as the Earth-Sun distance is responsible for the seasonal change in temperature?

Professor David Treagust was interested in scientific misconceptions (Cf. Coll & Treagust, 2003; Harrison, Grayson, & Treagust, 1999), although he preferred to call them “alternative conceptions”. I reject his view as suggestive that there existed multiple truths (perhaps conflicting) within the external world. This was against the realist stance and naturalised epistemology I had adopted in response to Popper, Quine and Russell.

I was using the paradoxes of relativity and quantum mechanics to thrust open a very small crack in my development of understanding of paradoxes.

I did not tie down my stipulated meaning until many years of study. My inability to devise a stipulated meaning for paradox was due to my confusion surrounding the logical, semantic paradoxes. Prior to their study, I was willing to call any scientific anomaly a paradox. Now, I was beginning to appreciate the differences from a logician’s point of view.

In Alfred Whitehead’s book, *The Organization of Thought, Educational and Scientific* (1917), reviewed by Philip Jourdain (1918), Whitehead is quoted as saying, “The mind untrained in that part of constructive logic which is relevant to the subject at hand will be ignorant of the sort of conclusions which follow from various sorts of assumptions, and will be correspondingly dull in divining the inductive laws”. (Cited in Jourdain, 1918)

What I did, when teaching, was provide a logical framework for my students to understand the tentative nature of evidence within science. This would then be the true place for Popper’s ‘logic of scientific discovery’ within my educational program.

I sent correspondence to Professor Mark Colyvan about the EPR Paradox.

> Non-locality is a consequence of the Copenhagen Interpretation of Quantum Mechanics. Einstein disallowed non-locality and hence confirmed the EPR paradoxical. The solution to the EPR paradox is to accept non-locality, however intuitively false it appears. Bell's Theorem is proposed as proof of non-locality however it is based upon unsound statistical principles. (Blanton, 1996)
>
> Based upon my view that paradoxes are man-made, sophistic was a bad choice because it involves deliberately misleading statements, problems as opposed to 'real' ones.
>
> Evidence of non-locality is dubious, why accept it when other explanations, Ockham'd out of the non-dubious evidence, clear the path to the conclusion that is not intuitively implausible.
>
> Paradoxes are anomalies (T. S. Kuhn, 1962) because they are incongruous within the existing paradigm.

I was trying to develop potential areas for investigation within my classroom. Physics seemed like a reasonable place to start.

> *Let's try 'all Cretans are liars'. A statement that is disallowed because it is self-referential. Paradox generate from fundamental flaws in understanding.*
>
> *The misconceptions of my students come in two forms, false abstractions and false logical processing.*
>
> *False logical processing can be shown up by if/then scenarios.*

My Philosophical and Logical Tensions

When I examined my philosophical beliefs using an online website contributed to by Stangroom (2001), cited earlier, pairs of beliefs were identified as being 'in tension', suggesting I expressed inconsistent beliefs. My overall tension score was 27% (halfway between low and medium). I was surprised that I had such inconsistency. The website suggested, "...please don't take this too seriously!" Stangroom's attitude to resolving the tensions was what attracted me. The website states, "What this means is either that: (1) There is a contradiction between the two beliefs or (2) Some sophisticated reasoning is required to enable both beliefs to be held consistently. In terms of action, this means in each case you should either (1) give up one of the two beliefs or (2) find some rationally coherent way of reconciling them."

My students when faced with their own tensions could use this same process.

The two tensions evident in my own score were in response to the following questions:

1. Is morality relative?

2. Are there any absolute truths?

For the first question I had to reconcile my belief that morality is a matter of culture and convention with my condemnation of acts of genocide. For the second question I had to reconcile my reported agreement with the idea of no objective truth about matters of fact with truth being contingent upon culture and individual perspective. The second came as a bit of a shock. What? I didn't believe absolute truth! This was reconciled by admitting my inability to determine if I had found the absolute truth, in spite of my firm 'realist' belief that I could know truth, at least scientific truth.

I completed a test of logical thinking through the same website. The thought that I was not consistent in my application of logic was a surprise at the time but it was also perfectly understandable. I concluded that the questions asked were themselves inconsistent and therefore I must yield contradictions. By inconsistent, I probably was thinking about the concept of logical 'vagueness'.

The Test of Logical Thinking (T.O.L.T.) I undertook was a variation of the Wason selection task devised by Peter Wason (1966). The T.O.L.T. can find the ability of subjects to detect exceptions to the conditional reasoning rule in the form of: If P, then Q (*modus ponendo ponens*); mentioned in previous chapters.

If I base a belief on defective reasoning it is grounds for rejecting my belief and therefore it would be essential for any student of mine or a colleague teacher for that matter to identify their failure to use conditional rules appropriately. Jeremy Stangroom (2001), author of the website mentioned argues, "...if we systematically, unconsciously, reason badly, then the extent to which reason actually acts as a restraint on belief is a moot point."

The T.O.L.T. indicated I was unusually consistent with my application of the form *modus ponendo ponens*. According to Stangroom, 75-80% of people get the test wrong and the level of education doesn't have much impact on performance. Stangroom reports, "Moreover, even training in formal logic seems to make little difference to a person's performance!"

Stangroom reported the work of Leda Cosmides and John Tooby, which suggested that the human mind has not developed reasoning procedures for detecting logical violations of conditional rules. Cosmides and Tooby, according to Stangroom, suggest that the human mind *can* detect conditional violations when there is a cheating context. Perhaps this is the rationale behind Aristotelian virtue ethics. Aristotle's *On Rhetoric* presents *nemesis* as the emotion of being pained at undeserved good fortune of others. People should reap as they sow and therefore undeserved success is the cause of pain and frustration for others.

What are the implications for my desire to teach students to reason effectively? The following illustration using an example of a task I set my students to challenge their capacity to reason casts light on the matter.

The Paradox of the Ramp – a case study

I constructed, 'The Paradox of the Ramp' for my students.

All my students could appreciate this paradox because of their study of Galileo's inclined plane as a model for scientific inquiry. My colleagues on the other hand, rejected the paradoxical conclusion and sort about finding a flaw in the logic or a false premise upon which I based the apparent paradoxical conclusion. They were unable to find either quickly. Both my colleagues appreciated after some time that the Paradox of the Ramp had led them to reassess their own understanding of the concepts of kinetic and potential energy, as well as the concept of infinity and the notion of an ‘ideal’ ramp. The Paradox of the Ramp was a type of Sorites Paradox.

It became apparent to me that my students’ logic went something like the following:

Any slope would produce a finite acceleration. Infinite time would be required to roll down an infinitely long ramp. Infinite time combined with finite acceleration would lead to infinite velocity, contradicting logically deduced constant velocity consequent from accepting the premise that the kinetic energy and therefore the velocity would be constant as kinetic energy, in this case, is only dependent on the height of the ramp.

My students accepted *both* the ball’s infinite and finite velocity, a dialetheist approach reminiscent of Priest’s solution to the liar paradox referred to earlier. My teacher colleagues were unable to do this, constrained by the law of contradiction. Using a *reductio ad absurdum* argument they sort about identifying a false premise in the question.

Emerging now was a naïve-sophisticated dichotomy to explain the response of the student (naïve) and the colleague (sophisticated) based on the acceptance of the law of contradiction. I watched an evolution of sorts occurring as my students developed increasingly sophisticated understandings of their own scientific concepts. It was unsatisfactory to leave my students in their comfortable position of denying the law of contradiction.

I thought Mark may be able to help me with developing my idea that my students’ conceptual understandings were evolving.

> Do you suggest that the use of an analogy with evolution is appropriate?
>
> This naïve view of evolution is one of gradual change. Stephen Jay Gould (2000, p. 81) suggested in 1972 that long periods of stability were followed by brief periods of rapid change, Gould called this theory, Punctuated Equilibrium. This would be

the view that I hold of evolution, it is strongly suggestive of paradigm shifting even within the evolutionary context.

Students' minds resemble scientist's minds at an earlier stage of scientific evolution. Ontogeny following phylogeny, the recapitulation theory of Ernst Haeckel was the title of one of Gould's books

My thought became focussed by the works of Leona Schauble (1990) and Deanna Kuhn (1989).

Their [my students] naïve views are based on common sense lore and not observation. Therefore what is real to them is only what they can observe that is in accord with their common sense lore. Even after seeing evidence, students can maintain misconceptions because of the paradigm they operate from within. They will not budge.

In the English vernacular language, technical words can have vague definitions that lead to confusion, for example, students may say, "The acceleration got faster"; and, "Lead is heavier than aluminium". Vague usage leads to misconceptions which persist if left unchallenged.

A scientist may say, 'Acceleration increased' and 'Lead is denser than aluminium'. The first statement is the meaning intended by my students, however, the second statement is not the meaning intended by my students who persist with thinking lead is heavier than aluminium unless I challenge their naiveté by asking them to weigh a small piece of lead and a large piece of aluminium. Students readily conceptualise acceleration but initially struggle with the concept of density.

The elimination of misconceptions arises through engagement with conflicted theory and evidence. What can this simple example tell us about the potential for the development of student misconceptions in the absence of any conflict?

Questions such as, 'What do you know about evolution?' lead to the following student answers: chimps evolved into apes into men, evolution is slow and gradual, evolution leads to improvement, evolution is purposeful, and the individuals direct evolution. Adults express Newtonian misconceptions. Scientists know Newtonian mechanics holds true for modest-sized objects travelling at modest speeds, and consider this form of mechanics valid under those conditions. The use of vernacular language by adults with only a limited scientific background should accept some of the blame for students' apparent misconceptions.

A Picture of the Universe – a case study of memic transfer

Another example occurred when I asked my 15 year old grade 9 students to draw images of the universe from their own background knowledge. They had demonstrably naïve views of the universe that I describe as Ptolemaic in perspective. Their diagrams were world-centred and zoned in accord with Ptolemy and represent the consequences of failing to challenge naïve concepts, which had not occurred until this point in their science study.

I wrote in my journal my thoughts on the matter as a set of statements (S).

> *S1 - The expert scientist maintains the set of all concepts within one field.*
>
> *S2 - The teacher maintains a sub-set of the set, S1*
>
> *S3 – The student maintains a sub-set of the S2 and S1.*
>
> *The example of Neolamarckism versus Neodarwinism paradigm conflict.*

My students were simply repeating images that they had seen from television documentaries or children's books and hadn't processed what this would mean for the validity of the model that they held inside their heads.

Where does the scientific community present paradoxes of omission, such as this? Retroviruses such as human immunodeficiency virus (HIV) can cause permanent inheritable changes to the human genotype. What explains the apparently decreasing entropy associated with the diversity of species from which natural selection selects when the Malthusian crisis forces selection from the available genome?

> *Maybe paradox/anomaly doesn't yet exist, so there is no pressure for a paradigm shift.*
>
> *The word paradigm is used inappropriately by many when they use it in a non-specific way.*
>
> *Paradigm shifts only occur when the change agent hasn't got a substantial personal investment in the existing meme (something that came through from Thomas Kuhn)*

Memic transfer of information, referred to above, came from reading Eric Drexler's (1996) *Engines of Creation*. It was he who referred to Richard Dawkins concept of meme. Synonymous with gene, the meme transfers from human brain to human brain by imitation. The false concept, 'the acceleration got faster' would be an example of memic transfer by students, repeated, unquestioningly, due to lack of arousal of cognitive conflict.

I bring these two ideas of meme and paradox together in the following example. According to Feynman, The Twin Paradox is interesting because people consider it paradoxical. They do this because they do not believe all motion is relative. For those people who believe all motion is relative the Twin Paradox is not a paradox because the conclusion of the Twin Paradox is logical. A person like relativistic physicist Luise Lange (1927) did not see the logicians' paradox—he simply accepted the conclusion. The conclusion that the travelling twin and the stay at home twin would not be the same age.

Phlogiston Theory Part 2 (see Part 1 in chapter 5)

I thought Phlogiston Theory (PT) could provide opportunities for my students to challenge their memicly accepted concepts. My comments recorded in my journal on the topic suggest that I saw some limited potential for PT to act as an exemplar for theory change. I had concluded that the nature of science, what

I refer to as ‘NOS’ was more important for my students’ development than scientific knowledge. (Cf. Allchin, 2003; Clough, 2000; Hogan, 2000; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Niaz, 2001; Ryder, Leach, & Driver, 1999; W. A. Sandoval, 2005; Schwartz & Lederman, 2002)

> *Phlogiston theory – a potential paradigm shift referred to by Mark Colyvan also referred to by Thomas Kuhn.*
>
> *Is it not just an example of evidence refuting existing theory?*
>
> *The old established order view new evidence that refutes established theory as paradoxical as a defence to sustain the old regime. At that point the theory has ceased to evolve and has become dogma. They view information that appears to contradict existing theories as anomalous again as a defence mechanism. This is a strategy similar to Kuhn’s theory.*
>
> *Paradigm – a set of abstract beliefs*
>
> *Do we change the full set or a subset?*
>
> *It probably isn’t humanly possible to change the complete set of beliefs.*

Phlogiston theorists solved difficulties with their theory by allowing phlogiston to possess negative mass, a somewhat counterintuitive belief. According to PT advocates, phlogiston releases when metals burn and therefore phlogiston must have negative mass because the metal ash increased in mass. Phlogiston had all the portent of myth, and caused the delay of the development of chemical science according to some. (Cf. T. S. Kuhn, 1962; University, 1997)

Lavoisier’s (Cf. T. S. Kuhn, 1962) reduction approach killed phlogiston theory.

I focus on the concept of scientific revolutions as propounded by Kuhn, witnessing consistently that student scientific revolutions were analogous with Kuhn’s scientific revolutions. The internal conflict in the minds of the students was similar to the conflict in the external scientific world. Misconceptions, paradoxes and anomalies led to alternative theories. My view appears supported by conceptual conflict research. (Cf. Biggs, 1990; Kang, Scharmann, & Noh, 2004; Laburu & Niaz, 2002; Latour, 1987; Lee et al., 2003; J. Sandoval, 1995; Watson, 2002)

Students appear to have a lower 'inertia of the mind' and uniformly allow the novel in their experience to force conceptual change at a rate that exceeds the rate shown in the elderly. According to my students, 'elderly' would appear to be anybody over the age of 25 years. The weight or depth of the students' ideas and the velocity or rate of acquisition of new ideas are both shallower and quicker respectively, the students' possession of a lower number of deep understandings makes them more willing to shift paradigms. Perhaps explaining why so many of the world's recognised greatest thinkers, for example Albert Einstein, are 'change-agents' only in their youth.

I chose to teach Phlogiston Theory as a genuine theory, or at least to claim its truthfulness and then allow my students to challenge PT theoretically after they discovered the need for negative mass to explain the observation of increased metal ash mass post-combustion. My students found it incredulous to support negative mass for phlogiston. Certainly many students do objectify heat and it would be likely that they would persist with Phlogiston, in a similar way to Joseph Priestley, if I had not dealt with the concept of heat earlier.

> *If, " 'S - Nothing is known with absolute certainty' then, even the statement S, is uncertain".*

My version of the classic, 'All generalisations are false' was actually in response to the film *City of Angels*, one of the characters said to the actor Meg Ryan, "Some things are true whether you believe in them or not." Feynman's left-handed frog provides the opportunity to consider many of the underlying assumptions which may contain misconceptions but studying the assumptions also increases the complexity, perhaps unnecessarily.

Werner Heisenberg's (1999) two anecdotes provide a way of understanding the world from my Positivist's perspective. The first was, "…don't create a visual pattern [such as a left-handed frog], know the measurables" and the second was that, “…in order to understand a system you must only know its transformations.”

In my journal notes I acknowledge that I contradict Heisenberg when I regularly make sense of ideas by drawing diagrams of a black box. The black box represents the hazy scientific concept that explains the transformation of a set of observations, in other words the causal links.

I was soon about to embark on my own, Schrödinger inspired, black box experiment.

The Lure of Certainty

> I think, however, that there isn't any solution to this problem of education other than to realize that the best teaching can be done only when there is a direct individual relationship between a student and a good teacher—a situation in which the student discusses the ideas, thinks about the things, and talks about the things. It's impossible to learn very much by simply sitting in a lecture, or even by simply doing problems that are assigned… (Feynman, 1998, p. xxv)

Friday August 21 1835, the Sun newspaper in New York, publishes a story copied from the Edinburgh Courant—tucked away on page 2. The story suggests that Sir John Herschel made some astronomical discoveries at the Cape of Good Hope. I introduced *The Moon Hoax* in Chapter 8.

The following Tuesday, the 25th August, the story made front page news. The stories' author, reporter Richard Adams Locke, a friend to both Walt Whitman and Edgar Allen Poe was as accustomed, as his friends, to the use of irony. This previously mentioned story was an example of how the need to be certain of the truth lured me.

The traditional epistemology of the, "Cartesian Project" is rejected by Quine as a hopeless normative project which should be replaced by his naturalised epistemology or science of belief. Quine describes how I proceed with science knowledge development but not ostensibly how my students should proceed.

A thought stimulated by reading, *The Picture of Dorian Gray* by Oscar Wilde.

> *If I, in science, can't prove anything true yet can falsify a statement, I can therefore, by taking the negation and falsifying it prove the preceding statement true. Does this mean I can't falsify anything?*

I constantly tell my students that it is technically impossible to prove, for example, 'All ravens are black'; simply because of the difficulty in examining each and every raven. Ornithologists need to examine all ravens to prove the statement true in an absolute sense.

Although the existential statement, ‘All ravens are black’ could be falsified, or proven false, by reference to a single non-black raven, this notion is confused by the suggestion that blackness defines the object raven and therefore an object that isn’t black is by definition not a raven. In reality, as Thomas Kuhn points out, it is unlikely that a single instance of disconfirming evidence would falsify a genuine scientific theory; falsifying a statement held greater sway with me as a practising scientist and hence I was lured by Popper’s attitude toward prioritising his falsification principle. Nickerson’s paper (1996) explains the limitations of a single piece of disconfirming evidence. I found his presentation of Hempel’s Ravens one of the most eloquent I have read.

As an example, the scientific statement or theory that, ‘All objects travel slower than the speed of light’ is logically equivalent to the statement, ‘No object travels faster than the speed of light’. What evidence is required to falsify the two equivalent statements? Remember in science it is usual to assess pairs of statements—this and not that.

Many objects are examined travelling and their speed is measured to be less than the speed of light, supporting but not proving the statement, ‘No object travels faster than the speed of light’. To falsify the statement I must find a single object travelling at super-luminal speed. Finding evidence about the following statement, ‘All object travels slower than the speed of light’, one single example of an object travelling would falsify the statement. Finding that many objects travel slower than the speed of light does not prove, ‘All objects travel slower than the speed of light’. The observations merely support the statement. Inductive proof is elusive. The strength with which we can hold this belief is great because we have measured many objects and found that in no case, the speed of light exceeded.

Popper claims that experiments that have the potential to prove a statement false hold greater merit than experiments that provide supportive evidence. The reality of science is that pairs of statements are examined when good methodologies are employed; A and ¬A (the opposite of A), simultaneously validating A and falsifying the negation of A (¬A), however for expedience we examine openly only A. So it seems that the thought recorded in my journal was in error, falsification of the negation of A was not the logical equivalent to the proof of A. For it was one out of many possible observations and therefore contributed only an infinitesimal probability.

In *The Moon Hoax* (Locke & Nicollet, 1975) a passage illuminated the feeling of discovery that was associated with my journey through my own labyrinth, "It appears to be as natural for the human mind to be craving after the wonderful, the mysterious, the marvellous, and the new discoveries, as it is for the physical appetite to desire food, drink and sleep, and thereby as it were constantly attempting to lift up the veil that hides incomprehensibilities from our vision" (p. v).

According to Sainsbury (1995), the branch of philosophy known as confirmation theory (referred to earlier, see Rudolph Carnap) provides general principles for the determination of the quality of evidence, "These attempts [to provide general principles] have given rise to surprising paradoxes. Understanding them [the surprising paradoxes not the general principles] will lead to a better idea of the nature of evidence" (p. 74).

Hempel's Ravens is an example of a Paradox of Confirmation that if studied, should according to Sainsbury, provide my students therefore, with a better idea of the nature of evidence.

Evidence I determine to be good somehow 'feels' right, a sentiment shared by my student Beatrice and others in a previous chapter. The tuning in of this 'feeling of quality' is part of the armoury of any accomplished scientist. Some contradictions are true.

I noticed, reading John Barrow's (1999) book, *Impossibility* again that Graham Priest's name cropped up and maybe the seed of dialetheism had grown from this initial immersion reading Barrow's book; in spite of my complete lack of awareness of Priest or dialetheism at that time.

Barbara Koslowski's, *Theory and Evidence* had indicated Piaget as the 'starting point' for literature examining children's beliefs about causal mechanisms. Koslowski also mentioned Deanna Kuhn's (1989) work as significant because of the way in which it shows that student's theories are reconciled with new evidence. Tversky and Kahneman's research published in 1974 showed that students' lack of scepticism would often lead them to override base-line information when they possessed a rudimentary theoretical understanding.

Failure to remain sceptical of their theoretical understanding leads students to draw irrational conclusions. Koslowski was showing me the need to teach my students, 'sophisticated scepticism' where concept knowledge is considered tentative and not certain.

Capturing the novel relevant language

I asked my students to determine the output of their own domestic microwave ovens by heating 250mL of water in a vessel. All my students were cognisant of the need to ensure the validity of their experimental data by taking repeated measurements of the change in temperature of water. Only one student, Lizzie however, deemed the length of time the microwave was in operation would impact upon the outcome. All but this one student had made the assumption that the relationship between the change in temperature and the heating time would be linear. Based on this false assumption the majority of students were unable to make sense of their anomalous data that was in disagreement with the output statements made in the manufacturer's notes.

When I questioned Lizzie as to the reason why she had chosen to examine the output of her microwave oven over a series of different heating times her response was that, "due to the absorption of heat by the vessel" she expected that, "the longer the water was heated, the less heat goes into the water." Lizzie had, in this case, greater understanding of the concept of calorific heat and had accounted for the conduction of heat by the vessel. Lizzie did not view her results to be not anomalous, instead her results agreed with her prior theory of heat.

Lizzie was able to design a more effective test for the determination of the output of the microwave oven, in this instance Lizzie has concluded falsely that, “less heat goes into the water” her words imply that the microwave energy was directly changing the temperature of the vessel.

When questioned further, Lizzie demonstrated that she was aware that the microwave oven was indirectly heating the vessel after initially heating the water. This example confirms my thesis that lack of higher order logic or a language of logic to communicate her understanding, Lizzie was initially unable to clearly state her understanding. A naïve teacher may have fooled themselves into thinking that Lizzie’s explanation was deficient.

It was this student’s observational statement that led me to conclude the possibility that students’ theoretical understandings were different to their statements about their understandings. It may well be that my students possess greater understanding than their statements would suggest and simply lacked the marginally more complex language to clearly report their understanding either verbally or in writing. The teacher-student conversation suggested earlier by Feynman would provide very useful examples for student teachers I would supervise over the next few years.

Koslowski (1996) reports, “The most basic conclusion is that at all ages, but especially among younger subjects; there is a fairly robust inability to coordinate theory and evidence. Furthermore, this inability is intertwined with a meta-cognitive inability to think *about* theories rather than *with* them” (p. 31). My conversations with Lizzie and other students in Lizzie’s class suggested that an alternative exists where the apparent lack of coordination was due instead to the absence of complex language, yet uncaptured by the student, but necessary to demonstrate their coordination of theory and evidence.

Failure to capture the 'novel relevant language' is the cause of the lack of coordination of evidence and theory. The 'novel relevant language' is, I believe, the language of logic.

Koslowski's research (op. cit.) indicates that theoretically rich environments aid scientific reasoning. Developing theoretically rich environments was the direction in which my research lay.

Koslowski also suggests, "…to demonstrate that subjects are reasoning in a methodically legitimate way, one must demonstrate that subjects are relying on considerations of theory or mechanism in ways that are judicious rather than mechanical." In her 'General Summary and Conclusions', Koslowski asks the question, "What constitutes rational reasoning?

Koslowski's criticism of theory independent covariation-based, Humean model of scientific reasoning stems from her demonstration of two critical points. In her words,

> First, a reliance on theory or mechanism is a legitimate (indeed, necessary) aspect of scientific thinking because information about mechanism is evidential. Second, because science is cumulative, considerations of causal mechanism sometimes lead us, appropriately, to treat hypotheses as working hypotheses that can be informed by, and revised (rather than rejected) in the light of, anomalous evidence.
>
> …what students ought to be taught in order to teach them to reason scientifically [rationally] (p. 275).

I wondered about the same educational question that emerged for Koslowski.

My view on what ought to be taught was a greater appreciation of the evidence for theoretical understandings (the mechanisms) and the language of logic and so I was reaffirmed in my position of teaching rather than avoiding such theoretically rich concepts as: Tectonic Theory, Evolutionary Theory, Atomic Theory, and Energy and Matter Conservation Theory.

My perspective on what to teach students in order that they reason scientifically was the examination of the evidence both affirming and disconfirming pertaining to each domain utilising the logic forms *reductio ad absurdum* and *modus ponens.*

In their book, *Imre Lakatos and Theories of Scientific Change* (1989), Ostas Gavroglou and others quote Karl Popper's (1972), *The Logic of Scientific Discovery*, "What is true in logic is true in scientific method and in the history of science." (Gavroglou, Goudaroulis, & Nicolacopoulos, 1989) This struck a chord and led to further examination of the writings of Lakatos, Popper, Feyerabend and Stephen Toulmin in conjunction with Kuhn's paradigm shift idea.

It is Lakatos' demarcation criterion that advises us that Kuhn cannot be correct because all new theories having stemmed from earlier theories must include these earlier theories. This was presumably why Mark Colyvan had rejected Kuhn's paradigm shift notion of the progress of science.

The arrival of four new books; *The Educated Mind* (1997) by Kieren Egan; *Physics and Philosophy* (1999) by Werner Heisenberg and the two volume *Collected Works of L.S. Vygotsky* (Vygotskii, Rieber, & Carton, 1987) excited me. Egan's Imaginative Education Philosophy opened up an increasingly divergent list of possible strategies for teaching and learning. My diary indicates a cacophony of ideas flooding my mind.

> *All generalisations are false.*
>
> *Popper [falsification] leads to high verisimilitude.*
>
> *There is no novel idea in modern and contemporary philosophy.*
>
> *Popper suggests our propensity is toward indeterminism, the doctrine of not all events being wholly determined by antecedent causes.*
>
> *Laplacean doctrine of scientific determinism.*
>
> *Charles Sanders Peirce (1910), "Everywhere the main fact is growth and increasing complexity" Perhaps a human fallacy!*

Vygotsky's (ZPD) Zone of Proximal Development

Rousseau understanding the nature of development of the student is key.

Both John Dewey and Jean Piaget were influenced by Rousseau.

Rousseau discovery method may be the precursor of the Vygotskian pedagogy.

It was Egan (1997) whom I found most eloquent. He identified what appears to be the ideal goal of the science student,

> What is attainable, though, is the sceptical, philosophical, informed mind that energetically inquires into the nature and meaning of things, that is unsatisfied by conventional answers, that repudiates belief in whatever cannot be adequately supported by good arguments or evidence, and that embodies the good-humored corrosive of Socratic irony (p. 18).

Unfortunately what, "good arguments or evidence" mean, Egan does not explain. Egan does suggest that language generalises and is abstract. I wondered at the time:

How does this sit with the paradox on a previous page that all generalisations are false?

Egan (op. cit.) ironically suggests that he may be wrong but meta-cognitively promotes the telling of stories. Egan sees science teaching as storytelling; stories about the struggle of human lives,

> We tend to see the curriculum as a body of knowledge—knowledge about science, history, mathematics, geography, and so on—and we tend to see teaching as the skilled communication of this knowledge to children. If we begin instead to think of young children deploying mythic understanding flexibly in getting an initial grasp on the world and on experience, and we recognize story-structuring as a prominent feature of mythic understanding, then we are led to reconceive the curriculum as a set of great stories we have to tell children, and reconceive (recognize?) elementary school teachers as the storytellers of our culture (a recognition already in place in Waldorf schools) (Egan, 1997, p. 64).

Egan is keen to limit the fall-out from his apparent rejection of science as knowledge by emphasising the reformed view of curriculum knowledge in light of the human experience.

> This move need in no way diminish the content of the curriculum, but it allows us to see it somewhat differently. Instead of seeing math and science, for example, in terms of particular skills, knowledge, and manipulations, we would see them as among the greatest of human adventures, full of drama, hopes and disappointment, discoveries and inventions, and of people in whose lives mathematics and science played important roles.

Further Egan suggests that,

> By seeing math and science not as disembodied pieces of knowledge or skill but as the inventions and discoveries of particular people, as product of their hopes and disappointments, their struggles and problems, we can begin to re-embed those subjects again in their proper human contexts, in which they initially had affective, as well as purely cognitive, meaning. (Egan, 1997)

Alternative conceptions are generally viewed in the literature as an adjunct to; or homonym of misconceptions. (see Treagust et al) My view is of alternative, feasible theoretical constructs that explain phenomena but are not widely accepted. The use of which may enable students to grab onto a 'human interest' angle in a similar way to the journalist.

Wolpert (1992) "Science involves an unnatural mode of thought."

Kieren Egan suggests that I interpret paradoxes ironically; in a fashion after Richard Rorty (Egan, 1997, p. 137). Egan defines irony as perversely disguised statements which he believes may be better stated literally. A better definition may be, 'a mode of speech in which the meaning is contrary to the words'. It derives from the Greek, *eironeia*, meaning simulated ignorance.

The pose of ignorance, which was used by Socrates to entice his interlocutors into making refutable statements, permanently fuses 'Socratic' and 'irony'.

When Egan (1997), makes reference to language as, “a self-generating labyrinthine prison that offered no way out to reality” (p. 138), he did so ironically.

At a professional development session at my school a colleague and I proposed a new adjective, after some discussion, irritating the Chairman. ‘Co-tortoiseness’ we it used to describe the act of ‘pulling one’s head in to allow others to slowly get things done even if you disagree’. I found the situation at the meeting appalling because discussion was stifled because the outcome, preconceived by the Chairman, was appearing to lose traction. I imagined an upside-down tortoise tied to the shell of another tortoise and on it I wrote: a = 1/m (Double the mass and halve the acceleration). The attempt of the Chairman to stifle the true dialogue decreased the rate at which we made progress.

Language interpretation is very personal in nature. The Chairman used his ‘non-specific’ metaphorical language to mislead his audience. In the following example a ‘Newshour’ program from the U.S.A. used the metaphor, ‘breeding ground of Islamic terrorism.’ Used in the sense of multiplying bacteria or mosquito infestations it does little to enhance dialogue. The tradition of using derisive or deceptive metaphor in this way goes back to its politically motivated use by the ancient Greeks and Romans.

Kieran Egan’s book was providing a greater understanding of the value of irony and the extensive history of the style. Several points made by Egan struck a chord and foretold of the need for maintaining scepticism about my own thoughts.

There appears to be a great deal of common ground between the use of ironic thinking and the use of paradoxical thinking. It may well be reasonable to use the two terms interchangeably; as many authors tend to do presently.

> *“The problem with educational theories is that the stupid pedagogue takes it as a panacea and rams the square peg in a*

round hole, to the delight of the author of the subsequent theories." (Egan, 1997, p. 194)

"Ironic understanding seems to allow one to appreciate more jokes - even the cosmic ones." (Egan, 1997, p. 200)

"History is one of the major tools we have for making sense of experience in a changing world." (Egan, 1997, p. 210)

"Inadequately educated minds are vulnerable to simplistic ideas; such vulnerability is improper in the citizenry of a democracy." (Egan, 1997, p. 228)

These ideas, expressed above, were synthesised into a coherent attitude toward the preparation of material for my classes. I found a way of applying Egan's theory in my own teaching. I had in fact been doing this all along but reading Egan had held a mirror up to my own theoretical framework, bringing it into jarring focus.

"What are the competing theories…?"

"What evidence supports these different theories?"

"How can one assess this evidence?"

"What further information would help one theory or another?"

Kieran Egan (1997), suggests that this practice, the practice of ironic or paradoxical understanding, "…leads students by a somewhat unconventional route to, what seems to me, a more abundantly educated life" (p. 238). Egan may have viewed this process as being, "unconventional", however, I had taught science only this way since the latter part of the 90s.

Kieran Egan uses Richard Feynman as an exemplar or illustration of the ironic teacher. Ironically, Egan chooses Feynman; for Feynman is recognised by many as a very difficult teacher to comprehend, entertaining nevertheless, but difficult. The popular image of Feynman, repeated by Roger Penrose in the introduction to, *Six Not-So-Easy Pieces* (Feynman, 1998, pp. vii-ix) tells of the truly entertaining quality of Feynman's lectures, which were always well attended, however, given the intrinsic difficulties associated with the material, the subject of Feynman's lectures, it is unsurprising that many participants failed to comprehend what was being said.

Feynman himself recognised this awkward reality in his preface to the 1963, 'Lectures'. He bamboozled his intended audience, the undergraduates, whilst the more sophisticated participants; mainly post-graduate students and Faculty members were the ultimate beneficiaries. This recognition of Feynman's weakness was certainly telling when I examined my own teaching. (Not that I would dare compare myself with the likes of Feynman) I could recognise that for a great majority of students this pedagogy of paradox was doomed to failure. It proved to be most valuable when teaching those students who were destined, because of their aptitude or fascination with science, to forge a career in the sciences.

Motivation for studying paradoxes

My thoughts of the juxtaposition of irony and paradox focussed upon the ironic philosopher and writer Jorge Luis Borges. Borges would later become the inspiration for the inclusion of my fictional short stories (see chapter 7) within my thesis as a means of allegorically communicating tentative resolutions to many teaching paradoxes.

Whilst writing fictional stories, I could be free to explore the paradoxes beyond the vice-like grip of the technical requirements of the discipline of logic.

I read Borges a long time after writing the short stories, rather peculiarly, not before. Borges writing, especially, *The Garden of Forking Paths*, *Pierre Menard*, and *The Circular Ruins* provided both inspiration and justification for the inclusion of my fictionalised stories in Chapter 7.

I chose each of the paradoxes, introduced to my students, to educate my students in the language and methods of logical analysis. Because the paradoxes had proven themselves to have qualities that allowed for strong student engagement I avoided the plunge into René Arcilla's abyss mentioned in earlier.

Werner Heisenberg also showed a propensity toward the use of irony or paradox in his writing. In spite of Heisenberg being a physical scientist and as such spending a lifetime 'discovering' the universe it was his rejection of the empiricism of Locke and Berkeley that led to his greatest contribution to the positivist's world view—The Heisenberg Uncertainty Principle.

Heisenberg (1999) recognised that the philosophy of Descartes had, "…penetrated deeply into the human mind during the three centuries following Descartes and it will take a long time for it to be replaced by a really different attitude toward the problem of reality." Heisenberg recommended the throwing out of the Cartesian Language way. Dualism was over-generalising and the paradox that all generalisations are false had taught me to be sceptical of binary structuring that resulted from the 'black and white' partitioning of concepts. Heisenberg implores us to study the transformations and not the system itself as a means to bypass the false generalisations. The methodology of examining the transformation of students between grade 8 and 11 seemed logical after Heisenberg's intervention.

Child psychologist, Jean Piaget in Vygotsky's Collected Works (Vygotskii et al., 1987) talks about traditional psychology seeing a child's concept as a deficit. It was this idea that led to the alternative idea that children's naïve alternative concepts have validity. Adult concepts can also have validity in spite of being in discord with preferred scientific models. Both, naïve adult and child concepts possess validity because the concepts have the capacity to provide motivation for conceptual change when examining the logic or consequences implied by their concepts, as when, for example, my colleague re-examined his theoretical understanding of the *Aurora Australis*. It is the logic that eventually leads my students or an adult to alter their own concept when it is they, rather than their teacher, who discovers the discordant nature of their own contradictory and unresolved views.

Children and adults are quite capable of simultaneously holding opposing views (dialetheist thinking). To demonstrate this notion I fashioned a thought experiment for some beginning grade 9 students.

In my thought experiment a two-pulley system is attached to a 10kg block and the free end of the rope is attached to a lever 'x' metres from a pivot and a force is applied to the opposite end of the lever '2x' metres from the pivot to lift the 10kg block. I asked my students to provide a prediction for the force required to lift the 10kg block using the lever attached to the pulley system. Students had previously examined pulleys and levers separately; this was the first time I asked them to consider using pulleys and levers together.

One student answered 10N other students answered 100N, 50N and 25N. The student who answered 10N was operating under the false assumption that a 10kg block exerts a force of 10N due to gravity, neglecting this error (the correct value would approximate 100N), the student claimed that because the two-pulley system has a mechanical advantage (M.A.) of 2 and the lever has a M.A. of 2 they cancel each other out. This student when questioned further revealed that they understood that the pulley system alone would reduce the force required to lift the block and that the lever used alone would decrease the force required to lift the block. Additionally, this student knew that simple machines such as levers and pulleys reduced mechanical effort, in other words, they offered a mechanical advantage, however, they concluded that the individual benefits would cancel each other when they used the systems in concert—an error of logic cause by the increased complexity of the problem.

With every individual who erred in their assessment, I aided my students to resolve the situation by using *eironeia* or simulated ignorance which led to the student performing the necessary experiments to answer the question. Students soon discovered that their prediction disagreed with the reality and adjusted their reasoning to accommodate the discordant observations. My students were mostly unable to apply this new understanding when given novel, yet similar, complex situations indicating to me what appeared to be their failure to apply the Law of contradiction suggesting that this Law is not known *a priori* (by reference to thought) and therefore implies the need to directly teach this foundation in the form of *reductio* arguments. The thought that students would not naturally use *reductio* arguments was completely mystifying!

Research, such as that mentioned by Stangroom (2001) previously, has shown that students taught a course on logic can persist with their own intrinsic logic flaws after completion of the course and thereby fail to answer questions of logic appropriately. Instead of directly teaching logic I was indirectly exposing my students to the argument forms in their attempts at resolution of paradoxes, in such a way they were able to apply their new understandings to novel situations. Later in the same year students were able to apply the principal of logically deducing a contradiction from a premise to deny the truth of the original premise. For example, logically proving objects of differing mass do not fall at differing rates by assuming firstly that two objects of differing mass do fall at differing rates and deducing a contradiction.

Alfred Ayer (1952), claims that the existence of logical and mathematical falsehoods increases proportionately with the, "…length and complexity…" of the problem (p. 86). Providing students the opportunity to break down, into manageable elements, my thought experiments or paradoxes is a reasonable activity. Logic could provide a framework for analysing problems. If a student's own logic leads to a contradiction it would be meaningful to direct the student toward resolution rather than avoidance or abeyance—their current, and persistent, stratagem.

The falsification, although guided by the concept derived from Popper, was rather the sense of logical discord (paradox) illuminated by the student example just indicated. When my student's own theoretical understandings lead them to an impasse or paradox they are compelled to follow Sainsbury's advice to resolve the impasse (Cf. Chapter 3 - The Story of Erasto Mpemba). The students' assumptions may be wrong, their logic flawed or the conclusion which appears unacceptable to them they nevertheless should accept.

It was the work of Deanna Kuhn and Leona Schauble, on belief revision, that most informed my thoughts in regard to the persistence of incongruent positions held by my students. Like Schauble and Kuhn, I too discovered that the bias demonstrated by my students was not resistant to the, “cumulative weight of evidence” (Schauble, 1990, p. 54). Schauble (loc.cit.) states that her results agree with the findings of Kuhn, Amsel & O’Loughlin (1988), in that the confirmation bias of the students, “…can be mitigated over time and with experience.” This view again reinforced the positive attitude I expressed about theoretically rich practical tasks.

I was struggling with the thought that my own ideas pertaining to paradox were an unsightly rehash of the ideas of others with no sliver of original thought. I hadn’t yet learnt to trust my instincts that what I knew and understood was original.

Finding my voice was a most difficult task, everywhere I looked I saw reflected in my own writings the voice of the others, others that I had read. The primordial scepticism of my youth was not the sophisticated kind that I later developed as a practising scientist. What is my purpose as a teacher of science? My purpose, as a science teacher, should direct my pedagogical approach in the same way that my research purpose directed my methodological approach.

Taking my sons to childcare one day; I was on my way out the door when I made a remark to one of the workers regarding a small toy that had been, ‘borrowed’ the previous day. “Apparently he doesn’t want to give them back,” I said. “Evidently,” said the woman standing directly behind me. It was clear from her tone that she intended to correct me. I nodded acknowledgement when I turned around to face her but said nothing more.

As I drove my car to school that morning I couldn’t help but dwell upon the comment. After consultation with the Oxford English Dictionary I noted that ‘evident’ and ‘apparent’ had identical meanings if ‘obvious’ was accepted as the preferred definition. However what is apparent is; seeming real or true but not necessarily so, and what was evident was; clearly understood.

When Leona Schauble's (1990), article spoke of encouraging complexity in patterns of evidence it flew in the face of the notion that simplicity should be sought when examining scientific concepts with students. The students' "conservation of invalid heuristics", led to their naïve conceptions and outright misconceptions. Schauble (op. cit.) was of the opinion that complexity led to the mutual constraining of theory and evidence, "…the micro-world [Schauble's model] was sufficiently complex so that a child who did not use valid strategies would be frequently confronted with apparent inconsistencies" (p. 55).

Here was the crux of the matter, my students and I were possibly viewing the 'evident or apparent' inconsistencies as either "obvious" or "seemingly real or true but not necessarily so" respectively and that may be the cause of my students' inability to recognise the inconsistencies as evident. Perhaps this would explain the inability of my students who on occasions fail to transfer, to novel situations, understandings from prior learning where they confronted apparent inconsistencies. My students were choosing to ignore the inconsistency, regarding it as an error on their part.

Bruno Latour (1987), did observe that, "In every one of us there is a scientist who is asleep, and who will not wake up until social and cultural conditions are pushed aside" (p. 185). Waking the sleeping scientist in my students was one of my purposes as a science teacher.

> *Both paradoxes and alternative conceptions are implicit in the fabric of science. It is therefore reasonable to ascertain their relation to each other and to the concept of evidence as it pertains to science. How study of both these philosophical constructs may effect student awareness of evidentiary logic in science is of primary concern.*
>
> *Secondarily, it is well noted that, complexification of understanding of the 'ways of science' is developmental and linked with increasing brain complexity, particularly the*

modulating role of the pre-frontal cortex. It is of interest to ascertain relationships between cognitive development and physiological maturity in late adolescence.

Does the study of paradoxes (scientific, literary, mathematical and philosophic) effect students' need for evidence to support knowledge claims, both the claims of others and knowledge claims they make themselves?

Prime Minister John Howard announces to the Australian community approval for stem-cell research and the legislative ban on human cloning and embryonic stem-cell research (embryonic cloning). Two days later controversial Italian reproductive scientist Dr Severino Antinori announced the first human clone to the world. The date of birth and the name of the mother were unspecified, and remain so. Given the rejection of his claim by Antinori's one-time colleague, reproductive scientist Panayiotis Zavos, the story, most probably, has been fabricated. Opportunities were taken for inclusion of this stem-cell and cloning science in my grade 10 curriculum. The academic controversy surrounding stem-cell cloning; the misinformation and rhetoric provided an excellent opportunity for using my paradox inquiry method.

This research is stimulated by personal observations of increase depth of scientific understanding by teacher and pupil after engaging in extensive interrogation of, both current and historical, alternative scientific explanations of phenomena. In particular, alternatives to plate tectonic explanations of continental drift, namely the expanding earth model; neo-Lamarckianism as opposed to NeoDarwinianism; creationistic as opposed to Neobigbangianism and an infinite expanding universe.

The use of paradoxes and storytelling is embedded in this researchers' pedagogy. The principal purpose was always as a condiment to the meat and potatoes dished up in the day to day teaching practice. The mind games involved in engagement in *puzzles of a paradoxical nature help to reinforce the fundamental principal of enquiry-based curiosity. Students able to write coherently about paradoxes were noted to be 'good' at science. Whether the study of paradoxes led to improved outcomes in science or 'good' science students were better at deconstructing paradoxes is not known. However one of the main challenges in the use of paradoxes was to encourage students to accept that to 'solve' a paradox was, as with the case of Eastern koans or Greek aporia, not the primary task [motivation].*

I noted the paradoxical advice of Sainsbury (1995), when he implores us to be sceptical of his solutions to specific paradoxes.

> On the other hand, I certainly would not want anyone to believe what I say without first carefully considering the alternatives. So I must offer somewhat paradoxical advice: be very sceptical about the proposed solutions; they are, I believe, correct (p. 3).

The comments of Kieran Egan coalesced into the Scepticism Paradox: (a version of the generalisation paradox). To maintain 'sophisticated' scepticism one must moreover be sceptical of scepticism.

A student approached me with what they had been told was a paradoxical problem. Kerry told me that his math teacher had asked him to share 17 sheep between 3 sons such that the eldest son received half the sheep, the second eldest received one third of the sheep, and the youngest received one ninth of the sheep.

The solution suggested borrowing (temporarily) one sheep from a neighbour; then giving nine sheep to the eldest son, six to the second in line, and 2 to the third son, and then returning the left-over sheep. Kerry's maths teacher had presented this problem to Kerry as a paradox, indicating that my learned colleague had used a naïve definition of paradox. Clearly, in this case, the maths teacher would know that the solution contained a fallacy and was using the student's attempt at detecting the fallacy as a teaching strategy. I indicated the problem was not paradoxical because it contained obvious errors of logic. The student had kindly indicated to me the difference between a simple puzzle (such as this example) and a paradox.

The desire to solve the puzzle *for* the student must be avoided by the teacher. This avoidance of solving the puzzle is interminably impossible. Avoiding solving cataclysmic paradoxes requires no such effort, hence their great supremacy over puzzles as a teaching strategy.

I rented a house out of necessity generated from building my own home. The open house days, which came as part of my rental agreement, were a pain but the price of the rental was too low for this deal not to be accepted. As circumstances sometimes conspire, one of the many people who traipsed through was the elderly father of one of the potential buyers. This retired Professor of Political Philosophy from the University of Western Australia was once Karl Popper's student. I asked what he could tell me of Popper and of his falsification principle because I was fascinated with my idea that confirmation and falsification are similar. Popper had made a name for himself just by reframing scientific confirmation.

> *"When we ask a question are we like this? We're really saying are we like this and not that? E.g. are we humans rational and not irrational?" J.S. Mill*

My notes suggest that the Professor viewed Imre Lakatos favourably and that Popper treated Lakatos very badly. I'd heard this before but was unfortunately, at that time, less interested in their personal stories; I could gleam little from the Professor about Popper's defence of the principle of falsificationism that was not available in his book, *The Logic of Scientific Discovery*.

> *What are the big ideas? What do we want our students to understand? What constitutes scientific literacy? Why is it most of the adult population is scientifically illiterate? The*

community is constantly exposed to examples of science fraud. Science is used as a tool for social control.

What are the presuppositions, biases, logic, reasoning of the insights that you import from an area of understanding? The interpretation of insight must account for tradition, logic and reasoning.

How should my thesis be judged?

I began planning to interview again, the students I had previously interviewed, (Chapter 8 - Perception, Authority and Truth - Interviews with students) based around four epistemological questions:

1. What do you claim to know?
2. How do you come to claim to know?
3. By what means do you justify your claims?
4. What biases do you bring to bear?

A science teachers' professional development forum held at the University of Tasmania's Launceston campus asked the question, 'How could enrolments in science at universities be increased?' I formed the opinion that becoming a science professional was like female sex determination. The simile goes like this: All human babies commence life as females; being transformed by the presence of hydroxyl-testosterone which triggers the transformation from female to male.

Something was able to transform some students into science undergraduates. I witnessed a transformation with Albert, who had no intention of studying science but ended up enrolling in three science subjects in his first year of college life, and then subsequently enrolled in a Bachelor of Pharmacy at the University of Tasmania. I now visit him from time to time when I have a script to fill for myself or my boys.

I participated in a program led by Professor Tom Barone of Arizona State University, *The National Conference on Narrative Inquiry*. I was sceptical of the value of such story-based inquiries; I viewed inquiries of this nature lacked the objective qualities that my science training turned into my biases.

Billy Charles Barnett would change this view; the certainty I clung to seemed less like a life preserver and more like a bag of bricks.

Chapter 10 – The Story Teller

> Billy Charles Barnett's story (Barone, 1993) would have seemed interesting but unimportant if I hadn't participated in Tom Barone's Lecture at the National Conference of Narrative Inquiry.

My own historical contexts, of which I have already spoken, clouded my original thoughts about narrative inquiry as a means for gathering worthy data. I had suggested to Professor Barone that his method was voyeuristic and its purposes were ill-defined—he suggested that I may not be the audience for his writing—an idea I viewed with cynicism. Barone began by informing people, who thought Billy Charles Barnett had little to offer outside the fascinating story that his was, how narrative inquiry could offer a new way *to know*.

I disagree that I was not the audience for his writing. I, and indeed others like me, raised in the traditions of empirical science, gain a great deal of insight from the narrative form. My notes nevertheless reflect that I was feeling that Barone's motives were questionable.

> *Also suspect an element of narcissism with statements like, "I learnt more about myself than I did about the subject of the inquiry." [One of Barone's comments]*

With the benefit of hindsight it is evident to me that what Barone claimed was also true of me and I owe a debt of gratitude to Barone for opening my eyes to another form of inquiry. A debt I may originally owe to Elliot Eisner, Barone's mentor.

> *Am I trying to find the 'one best method' to teach science? Do I believe 'pluralistic' theory teaching is better at exposing students to the true nature of science?*
>
> *Do I, as a science teacher intend to enhance certainty or multiple meanings which potentially leads to decreased certainty—really I am enhancing uncertainty. This is counter-intuitive or paradoxic.*

Narrative Inquiry

It was clear to me that a narrative approach was the best methodology to match with my purposes of my inquiry. My audience is the teaching fraternity. I am aware that very few teachers read monologic research: The language, being technical rather than vernacular.

Tom Barone suggests the use of vernacular language is one significant reason to use narrative methodologies. However, I did not want to avoid the scholarly language that was essential in the study of logical paradoxes and took solace from Stephen Toulmin's (1953) encouragement not to avoid theoretical discourse which can be made, "approachable", if there is socialisation into the language.

During the seminar Barone encouraged the participants to write a short piece, what he described as lean thematically relevant writing about a significant educational experience in our own lives. My writing follows:

> *Early in my childhood perhaps I was in grade 2, 3 or 4 at least I was somewhere between the ages of 7 and 10. I know this because I'd moved States when I was seven and lived in the Kimberleys for 9 months. I was asked by my teacher, the name and even her gender escapes me, to investigate the South Pole Explorers. Who had, in fact, reached the South Pole first? After thumbing the glossy red set of Encyclopaedia Britannica, bought for me by a favoured aunt, who was for that matter a practising teacher, I discovered Amundsen was the first to the South Pole. My teacher of the time marked my homework and reported that Scott was the first to the Pole. Having been taught by my parents, to play Crib at an early age I was used to holding my own, I launched into a tirade about why I was correct and that Scott was not, in fact, the first to reach the Pole. This event has stayed with me always. My actions as a teacher are shaped by the actions of this teacher.*

Narratives indeed influence teacher education. There is a strong oral tradition of storytelling within the teaching profession.

I was thus inspired along the path to a narrative inquiry method for my own research, it was natural for a teacher to tell stories; so when I wrote to Barone, I was already cognisant of narrative inquiries great import.

> Dear Tom,
>
> Thank you once again for the opportunity to interact with someone, in fact more than a few people, passionate about narrative research.
>
> I think, at the welcome reception, I mentioned my unease with narrative inquiry methods and although the unease still exists I am confident that it is the most appropriate method to examine students understanding of the nature of evidence in science.
>
> Part of the uneasy feeling I have surely does relate to my background in Thomas Kuhn’s “normal science” but also because some narratives I have examined appear voyeuristic and even narcissistic.
>
> You asked, during the last session, why I thought that the Simone film was not narrative research. I suggested that because it wasn’t balanced it didn’t qualify. I think you asked me my justification of the term balance. I sensed the question was for me to question myself.
>
> Sincerely
>
> Steve Lockwood

Scientific Inquiry

My Principal asked me to participate in an orientation program for grade 7 students. The usual introduction to science—never delivered by me—fell into the trap of entertaining students instead of introducing them to the true nature of science. The, ‘magic show’ version of ‘introduction’ disinterested me. I took to the classroom the intention to ask questions without giving answers. The questions I asked were: Are seeds alive? Can metal burn? Can metal dissolve? What is the shape of a water drop? How can you tell the difference between plants and animals? Pocket lint—what is it? I provided the grade 6 students with means to determine their answers through experimentation. What was interesting about the outcome was that it was quite natural for the grade 6 students to propose logical hypotheses about the questions. Many of the responses were of course, not true, yet they showed the capacity of these students to propose explanations and they based their explanations on information within their current declarative knowledge. (Cf. 1989, 2005; D. Kuhn, Black, Keselman, & Kaplan, 2000)

Barbara Koslowski (1996) and others had showed that the absence of a theoretical framework for understanding each of the questions did not allow the students to formulate explanations that were congruent with the available evidence which was evident to me as their science teacher.

An illustration would be the children's responses to the question, 'Are seeds alive?' The answers given were yes, no and not yet. When pressed, more questions emerged from the students themselves. What is it to be alive? What is dormancy, a question raised by one student? As difficult as it was to do, I resisted the temptation to answer the questions the students were asking. I very much enjoyed myself, listening to their responses.

The answers students gave to the questions developed by the students were dependent on the answer to my original questions. If a student thought that growth was required for something to be alive then they concluded that the seed was not alive as it was not growing, demonstrating that grade 6 students could use *modus ponendo ponens* logic. This logic form can be expressed as; If A then B, A therefore B. If the student thought that the potential for growth alone was needed for something to be considered alive then they would respond that the seeds were alive. A student answered that the seeds were not alive because they believed that it may be possible that the seeds, on display, would not grow and therefore these seeds were not alive. This student did not recognise that it was illogical to say, 'the seeds *may* not grow and therefore these seeds were not alive'. This student had experience growing plants from seed in their own garden and had discovered that not all seeds were viable. The Grade 6 students knew nothing of the process of respiration in seeds and therefore failed to link oxygen consumption to a living seed. Later when I asked this same question to grade 9 science students their responses were similar to the grade 6 students. Many grade 9 students believed that to be, ‘alive’ meant growth and therefore growth was essential for the seed to be considered alive. They falsely based their conclusion upon the well taught generalisation, expressed as an acronym, for the characteristics of living things. The acronym MRS GREN contains, ‘G’ for growth and students applied the generalisation to conclude that the seeds must not be alive because they were not growing.

The opportunity existed to draw on the paradox that, ‘All generalisations are false’. I sort simple illustrations of living things that were evidently not growing from my students. Many students pointed out that I was not ‘growing’, yet was obviously alive given my other characteristics. The concept of, ‘exceptions to the rule’ provided little difficulty to these students. There are always exceptions to rules but there are exceptions to the rule that all rules have exceptions? Some rules appear not to have exceptions, for example, ‘No object travels at super-luminal speed’. I would like to remind the reader once again of the Greek view of the notion of universals reported by Stephen Toulmin (2001)

> A universal was for the Greeks a *kat’holou*: this meant just the same as the English phrase “on the whole”—in the sense of “generally”—as it still does on the streets of Athens today. Aristotle did not claim that universal concepts were applicable invariably and without possible exception: in real-life situations, many universals hold generally rather invariably.

My students were capable of using a generalisation in the sense of *on the whole.* When Naomi Oreskes’ (1999) book, *The Rejection of Continental Drift* arrived, I was primed for propagating questions motivated by my conversations with the grade six students. Oreskes’ view of, “epistemic resurrections” directed my action. Oreskes states, “The history of science demonstrates, however, that the scientific truths of yesterday are often viewed as misconceptions, and, conversely, that ideas rejected in the past may now be considered true (p. 3)."

It was about this time that the Australian, Ted Steele was resurrecting Lamarckian Evolution. Although, what Steele was saying was portrayed by the scientific establishment as lunacy, his theory regarding the capacity of retroviruses to effect change in the genome was certainly plausible. I would later include this controversial story in my teaching of evolutionary theory.

Ironic Inquiry

My second son's premature birth in early August and the consequent weeks of hospital visits coincided with both my wife and eldest son contracting pneumonia. It wasn't until January, some five months later, that I could return to my studies—ironically inspired by the song *Gloomy Sunday*, sung by Nina Simone, and Samuel Beckett's play, *Waiting for Godot*. The story behind Gloomy Sunday is fascinating and reminded me of the, 'The Moon Hoax', reported earlier, because of its controversial nature and the difficulty I had pinning down any truthful detail.

Beckett won the 1969 Nobel Prize for Literature, because of plays like, *Waiting for Godot*. His writing style is always described as pure, economical and truthful but it is also ironic; using oxymora as a literary tool when he juxtaposes opposites. Listening to Beckett's characters say, "The roaring silence" and "relieved and appalled", reminded me of the paradoxes I neglected and reinvigorated my own investigation. Beckett's character, Eadie (Vladimir) said, "Things have changed here," when evidently, for anybody who has seen the play, they had not. My tacit knowledge said otherwise.

Things had both changed and stayed the same—paradoxically.

> *What is irony's purpose? Is it not a strategic choice?*
>
> *When authors use irony they do so to explain their own feelings of lack of control over the elements they observe/interpret.*

A literary genius, like Beckett, chooses irony purposefully. What John Stuart Mill (1973) says of fallibility can equally apply to irony. Mill says of fallibility, “While everyone well knows himself to be fallible, very few think it necessary to take precautions against their own fallibility.” Similarly, while everyone well knows himself to be ironic, very few think it necessary to take precautions against their own sarcasm—as irony slips into sarcasm in but the lash of a tongue.

Perhaps the following illustration can demonstrate this.

I listened to Professor Ros Arnold, Dean of the Faculty of Education, at the University of Tasmania say, “…let me put it a little easier for educators to understand.” Arnold was, ironically, speaking at my school about empathic intelligence.

Arnold supported the views of Antonio Demasio, particularly his rejection of the dualism made synonymous with Descartes. Demasio chooses to combine reason and emotion claiming that the mind-body duality of Descartes is an artificial construct of a pre-sentient world when supernatural religious explanations were prevalent. Demasio believes Descartes bases his theistic philosophy on unregulated anthropocentrism. Descartes’ location of human beings, “beyond the laws of nature” places them firmly in the land of ignorance in my opinion.

Arnold’s rejection of Descartes on the basis of Demasio’s brain research needed questioning, as I was sceptical about Demasio over-claiming and Arnold’s reliance on her position of authority, so I wrote a request on my School’s white-board stating, “I request equal time to refute the position of Professor Roslyn Arnold, Steve”. My vice-Principal rubbed this message off the main whiteboard inside of one hour, so I rewrote the message on a less used white-board at the other end of the staffroom. The message read, “Whosoever rubbed my request from the board opposite [“I request equal time to refute the position of Roslyn Arnold, Steve”] was your purpose to: stifle debate; be insulting; demonstrate your incapacity to spot a snake-oil salesman; all of the above; alternatively, didn't you think I was being serious?

This second message didn't last long. I was confused because my School had always prided itself on being a leader of educational practice yet was stifling intelligent debate and Arnold's presentation was on empathic intelligence.

A favourite poem of Alfred, Lord Tennyson came to mind, I think inspired by Beckett.

Tennyson's, 'Poets and Critics' had been pinned above my desk for a while.

> This thing, that thing is the rage,
> Helter-skelter runs the age;
> Minds on this round earth of ours
> Vary like the leaves and flowers,
> Fashion'd after certain laws;
> Sing thou low or loud or sweet,
> All at all points thou canst not meet,
> Some will pass and some will pause.
> What is true at last will tell:
> Few at first will place thee well;
> Some too low would have thee shine,
> Some too high – no fault of thine—
> Hold thine own, and work thy will,
> Year will graze the heel of year,
> But seldom comes the poet here,
> And the critics rarer still.

The following day I wrote my own haiku on the whiteboard:

> All Fred could do was,
> Lord it over ten of 'is sons.
> For he was neither poet nor critic.

Strangely this quip gave me solace and stranger still the words remained on the board until I rubbed them off two weeks later. I suspect that the person who had erased previous messages revered Tennyson's writing. I never did have the opportunity to speak about the claims of Professor Arnold.

I decided to read Michael Polanyi's (1967) *The Tacit Dimension*.

What is it I really want to achieve?

I find it fundamentally important to know how children/adults make decisions about believing ideas. In particular scientific ideas, however, their choice to believe other ideas such as paranormal/supernatural. I sometimes attempt to convince children of ideas they find counterintuitive. The concepts fall into two categories. Tangible observable and intangible unobservable. The first category is possible to witness, yet even so, some students may continue to reject the teacher version of reality, instead becoming more adamant that their knowledge claims are valid. The second category is often unassailable. Yet people may believe an explanation. Why do folk believe crap?

To analyse this last question I asked my grade 10 physics class the ramp problem below. This problem is not to be confused with, 'The Paradox of the Ramp', which being about an infinite ramp was not a problem; it was more like a fallacious puzzle. The ramp problem fell within the tangible observable problem category.

The Ramp Problem

Three ramps (A, B & C) were drawn such that each ramp was 1m high. Ramp A possessed a horizontal length of 5 metres. Ramp B possessed a horizontal length of 5 metres but was parabolic in shape, not straight like ramps A and C. Ramp C had a horizontal length of 20 metres.

I had great difficulty in asking an unloaded question about my ramps. I ended up asking, "Is there going to be anything different about the movement of a ball at the base of these inclined planes?"

Students had been studying Galilean inclined planes to explore the concept of acceleration for several weeks prior to me asking this question. The answers the students gave included: The ball is faster on ramp B (very popular response), the ball is faster on ramp A, balls A, B and C would travel at the same speed, and the ball will travel slower on ramp C.

It was clear from the majority of answers delivered by my students that they poorly understood the concepts of potential and kinetic energy.

The ramp problem highlighted my students' absent, essential, theoretical understandings needed to reason a solution to the puzzle. Information that they needed to constrain theoretically their understanding of the Galilean plane was missing.

My students prioritised ramp shape over vertical height as a causal mechanism. Given the simpler problem of three ramps of increasing ramp height and equal ramp length, students correctly label height as a causal mechanism, which they supplanted as a mechanism if the ramp only changes shape.

> *Is there something truly unique about the way I think and reason? Is it worth preserving? What will it mean? What is there to offer? How is it different? Is it arrogance? Is arrogance bad? Do others not understand? Why do they not see how simple the ideas are? Am I missing their point? Do they have one?*
>
> *Evidence and Action*
>
> *Example - management of an individual with aberrant behaviour.*
>
> *The administration is unable to resolve the problem due to the conflicting ideals and their inability to prioritise.*
>
> *All students have a fundamental right to an education AND No one has the right to impact negatively on the education of others.*
>
> *This polemic merely needs collapsing. Yet it is no mean feat to do so.*

Causal Mechanisms and the Nature of Evidence

Whilst watching, *The Secret Life of Us* on ABC television one of the characters referred to Jean Piaget's question to a young child named Juliana. "What makes the wind?" asked Piaget. Juliana responded, "The trees do." When Piaget asks Juliana about her evidence for the trees being causal Juliana answered, "Because I see them waving their arms."

Of the three Humean postulates Juliana was missing 'priority' one event preceding another. Contiguity and covariation were tangible and observable however priority, tacit knowledge of the wind, was known only to Piaget.

The Nature of Evidence

Student understanding of the nature of evidence. One of the fundamental, undeniable tenets of scientific inquiry is that no scientific concept can be proven correct; [they] merely support a particular view, although some ideas are supported by evidence so overwhelmingly strongly that the ideas in question are considered scientific truths. What are these scientific truths? What are the scientific ideas sitting outside the scientific truth set?

Sixty Minutes (Win T.V.) exposed the lure of conspiracy theories with a good illustration of where unsophisticated and unrestrained scepticism can lead. The program stated that 20% of America's population (60 million people) believe that the American Government had faked the Moon landing and a government conspiracy covered the fabrication.

All *scientific truths* are open to re-examination as a matter of principle yet the Moon hoax conspiracy, not *The Moon Hoax: A Discovery that the Moon has a Vast Population of Humans* (Locke & Nicollet, 1975) referred to previously (see Chapter 8), is indicative of the unhealthy consequence of unsophisticated and unrestrained scepticism. The Moon hoax also illustrates the point made that entrenched ideas are hard to shift even in the face of overwhelming evidence.

The *ad hoc* adjustment of conspiracy theorists' views is as unending as Tristram Shandy's autobiography. (Cf. Clark, 2002, p. 199) Buzz Aldren's solution—the delivery of a punch to the nose of conspiracy theorist Bart Sobrel, may be, in the circumstances, justifiable.

Why do 60 million Americans choose to believe Bart Sobrel's conspiracy theory? Why do people believe that the Tasmanian tiger lives on? If I assume that the beliefs of Sobrel and others are not unfounded and that something compels their acceptance of these views, in the same way that my students, unaware of the principle behind the transformation of potential and kinetic energy, make declarations of knowledge based upon their own flawed understandings, then like my students, the ignorance of 60 million Americans is not without its own kind of logic. Their logic is defective because it is based upon fallacy. Given their own acceptance of their false premises their argument proceeds logically enough.

Their logic is self-sustaining because it argues from false premises. The central premise of all conspiracy theorists is that, 'Governments require an ignorant populace'. Their logic becomes as unscientific as that of Lysenko's Michurinism and Mesmer's animal magnetism because their claims are not open to falsification.

Consider the following example. When my eldest son was two and a half years old he recognised that monkeys and apes were different from the presence or absence of a tangible and observable tail. He neglected the other intangible and unobservable appendix; the sure sign of an ape. Although it was me who put forward the classification; I know that it was my son's questioning that called forth the need.

He asked, pointing at an ape, "Why is that called an ape, and that, pointing at a monkey, called a monkey when they look the same?" I responded, "Apes don't have tails," rather than, "Apes have a vermiform appendix," to avoid the troubling follow-up questions from an inquisitive child.

Post-modernists would argue perhaps that the American conspiracy theorist's world view influences their interpretation or affects their interpretations. The world can be known. I can know the world. They can know the world. The worlds that the conspiracy theorist and I know are clearly different.

When two different world views meet, is it possible to have synchronicity? Can I amalgamate the duck hunter and the duck protector?

In Tasmania, duck hunting is both practised and reviled. A colleague stated his opposition to duck hunting by declaring his reason was based on, ‘The killing of native animals’. When I asked him if killing rabbits in the U.K. was wrong, he immediately saw his statement was inconsistent with other views he held and changed his statement in response to what he had perceived as a contradiction. According to my colleague duck hunting was still wrong but his justification was based upon, ‘The animal’s avoidable suffering’, rather than the impotent ‘native animal justification’. I chose not to ask my friend, ‘What if ducks could be killed without suffering?

There is no doubting that world views are culturally embedded, usually the voice of the powerful. Professor Arnold’s power was unfortunately ceded by audience complacency. Professor Arnold called upon her talisman, referring to her position as Dean of the Faculty of Education in her opening address. Power also resided in her references to intangible unobservable, to my colleagues, neuroanatomy. By invoking Vygotsky, Piaget, Stern and Descartes, Arnold closed all possibility of dialogue with her audience becoming instead an explicator.

I too invoke Piaget and others. Do I give my audience ample opportunity for language socialisation in the theoretical discourse which I ought to make approachable?

Storytelling is an important tool for science teachers but there is a need to guard against engendering *unrestrained* scepticism. If I wasn’t mindful of the impact of the difference between my declarative knowledge and the declarative knowledge of my students, my ignorance would be damaging. My students would swap one set of misunderstandings for another.

Chapter 11 – Swapping Fairies

> Part of the key to avoiding authoritarianism and indoctrination in classrooms — of school or university — is not to have teachers refrain from saying what they think, but rather to have students feeling free — and acquiring the skills, emotions, and habits they need — to react strongly and honestly to what teachers say. (Beck, 1993, p. 10)

The problem I now faced was no different to beginning work in any science discipline. I had discovered that my students didn't understand a great deal about mechanics but neither did they understand a great deal about evolution or plant science prior to beginning work within these disciplines either. So there was little difference when work on mechanics began.

After asking 3 classes of grade 10 students a set of questions (wording framed in a traditional fashion) regarding their understandings on the subject of Newtonian mechanics, prior to beginning that study I found most students were unable to answer the questions without demonstrating misconceptions. Other researchers have thoroughly exposed the recognised shortcomings of adolescents in this regard (Cf.Niaz, 2001; Roth & Roychoudhhury, 2003)

I believe that if they were asked within an appropriate context, students may be able to answer the questions well.

For example, can an object be truly still? If you were looking at a book sitting on a desk, from a space ship, would you see the object as still or moving? What force opposes the movement of the book under the influence of gravity? All students now see a support force being afforded by the desk.

The average scores of students is little more than what they would get if they guessed.

It appears that language was a barrier to communication.

Scaffolding is just connecting language sets. All manner of educational theories are built upon the connections between sets of language. (Cf. S.E. Toulmin, 1967)

I frown upon asking leading questions, what was really damaging, in this case, was that the questions I had asked were leading my students away from the understandings I sought for my students. This alternate form of leading questioning is equally blameworthy.

When is a monkey not a monkey? When it is an ape.

This sort of question is really the basis of experimentation, classification leads to experimentation, the discovery of the similarities and differences.

"It is likely that only with the aid of useful words and phrases and with a rich variety of concrete experiences that progress from the intuitive to the abstract, and that allow students to make mistakes and then critically reflect upon those mistakes, will these intuitive feelings become explicit and powerful conceptualizations during adolescence." (Lawson & Wollman, 2003)

Lawson and Wollman's article, *Encouraging the Transition from Concrete to Formal Cognitive Functioning - An Experiment*, originally published in the Journal of Research in Science Teaching (Lawson & Wollman, 2003) in 1976, states clearly the need for students developing an understanding of the language of the discipline as much as developing the concepts per se. Indoctrination and dogma could be essential ingredients of successful science teaching practice, provided the words of Beck (1993) are heeded and the students themselves feel empowered to question the knowledge claims of the teacher, including this teacher's need to question and be sceptical of just about everything.

Interrogate – View critically rather than quote your authors. People do so easily quote Foucault, Rorty, Habermas etc.:

drinking in their views dogmatically being converted to the faith by memic acceptance.

According to Robert Karplus (2003) the transition from concrete to formal reasoning, referred to by Lawson and Wollman (2003), is indicated by a student who, “Reflects upon his own reasoning to look for inconsistencies or contradictions with other known information” (p. S53), an indirect reference to the law of contradiction.

Here lay the link between the role of the science teacher and formal reasoning—the study of paradoxes. When a student is able to recognise paradoxes and reflect upon the reasoning that may be flawed or else according to Sainsbury (1995) the starting point or the conclusion has some, “non-obvious flaw” then they have attained the F5 status referred to by Karplus (op. cit.), this science teacher’s ultimate goal for his students.

In the past, I may have been expecting my students to attain formal reasoning without ever practising. The study of paradoxes provided training in and practice for the resolution of the contradictions within the declarative knowledge expressed by my students. The value of the development of formal reasoning by students is stressed by Karplus (2003) when he states, “Unless science courses are to become highly selective and admit only students who use formal reasoning patterns with ease, the formation of formal reasoning patterns should be made an important course objective (p. S55).”

I suggested to some students that they need to “touch the question”, or to find a way of making it real to them. Find an example where the misconception is illustrated. Jules, a grade 10 science student, received a grade of 16/17 for the true/false activity on force and motion misconceptions. Her score was 2 points above her next nearest rival (where n = 114).

The one question she got wrong was that she believed friction always impedes motion. I illustrated to her that by walking, turning around and returning to the start point her idea was *flawed. I said imagine doing that on ice. Jules immediately had the lights go on. I wonder if retested later would she still get it wrong.*

The mean value for the sample of 114 grade 10 students was 9.3/17 (mode and median 9.0/17). These values indicate that students were guessing. My questions, written classically in the sense that they appeared as I had seen similar questions represented by other teachers in the past, were misleading and did not reflect the genuine understanding of my students. I have no doubt that in Canada the friction question I asked would show Canadians know the benefits of friction.

It seemed that my students were ignorant of this type of question rather than being ignorant of the concepts in which I was interested. The case of Jules showed that little effort is required to facilitate change to a more scientific conception.

Is my role as a science teacher to convert students from a person with misconceptions based upon ignorance to a person who holds enlightened misconceptions? (The misconceptions are developed authentically)

In this view, I was asking my students to engage in *swapping fairies*, to exchange their mythical conceptions for my justified, yet to my students, equally mythical scientific conceptions. The first step in swapping fairies was necessarily to supplant their naïve conceptions.

Reading Kahle and Lakes (2003) article, *The Myth of Equality in Science Classrooms* I was struck by another form of inequality that existed besides the one referred to by these authors. Hewson and Hewson (2003) reiterate what I have already written elsewhere,

> Research into conceptions held by students has shown that there can be significant differences between conceptions of the same phenomenon. More significantly students often hold conceptions which are at variance with the scientifically acceptable conceptions, even after formal instruction (p. 87).

Is prior knowledge really necessary? Do I really have to start from knowledge of student's knowledge? Can somebody be taught something absolutely truly new or is scaffolding to existing knowledge unavoidable?

Hewson and Hewson (op. cit.), indicate several teaching strategies that can create the opportunity for students to exchange their flawed conceptions for more, "scientifically acceptable" conceptions. One strategy referred to as, "Exchange" seems to me almost equivalent to Sainsbury's method for resolving paradoxes mentioned earlier. Hewson and Hewson (2003) write of exchange,

> The aim is to exchange an existing conception for a new one, because they contradict one another and cannot, therefore, both be plausible. Since a student is not going to exchange a plausible conception for one which is seen to be implausible, it becomes necessary to create dissatisfaction with the existing conception as well as showing that the new conception has more explanatory and predicative power than the old (p. 88).

In the case of Jules, it was easy to provide evidence of a contradiction because of the concrete nature of her misconception then Jules exchanged her implausible view with the scientifically acceptable explanation. In more abstract fields this exchange becomes more difficult and it is likely that students will fail to grasp the implausible nature of their own claims.

Subsequently, I assessed a group of grade 9 students after an 8 week course on mechanics and simple machines. Prior to commencing the work, students possessed a naïve view of the concept of a simple machine as, 'A device with an engine.' The adjective, 'simple' was included and has been included in many other science programs because of this obvious need for differentiation of the vernacular 'machine' from the scientific conception.

The most difficult concept to grasp, perhaps the most difficult to relinquish, in relation to this body of knowledge relates to the concept of 'work'. Students retain the view that machines carry out less work (measured in joules as work is an energy term) in spite of repeated exposure to experiences that indicate otherwise. Of course, to conceptualise work students need to recognise the concept of potential energy. Grade 9 students viewed the concept of *work* in the vernacular sense and associated *work* with, ‘The ease to complete a task’ and as such they failed to shift to a more sophisticated view of ‘work’. Simple machines do decrease the amount of force (effort) required but because of friction, it is usual that more work is done when a simple machine such as a pulley is used. If students neglect friction then the work done with and without a simple machine is identical.

Novak (2003 originally published 1977) suggests conceptual bridging; linking abstract concepts with meaningful common experiences. My journal note of the time shows the direction I was heading.

> *Think of a scientific concept and construct (write) a paradox to represent the concept.*
>
> *The paradox is an abstract concept and therefore has the following possible restrictions.*
>
> *Only followed by formal reasoning (post concrete) students.*
>
> *May be used by concrete students to convert to formal reasoning.*
>
> *The experiments associated then have the capacity to eliminate alternative conceptions. A test such as TOLT or Wason's has the capacity to determine which students have the predisposition to tackle the paradoxes set [administered].*

It is Roth and Roychoudhury (2003) who warn of the consequences of simply using paradoxes as another way to show students the scientific truth when they say,

> If science is presented to students as a body of knowledge, proven facts, and absolute truths, then they will focus on memorizing facts and think that all knowledge can be ascertained through specific proof procedures embedded in the scientific method. If, on the other hand, students experience science as a

> continuous process of concept development, an interpretive effort to determine the meaning of data, and a process of negotiating these meanings among individuals, then students might focus on concepts and their variations (p. S115).

The Paradox of the Ramp was the means to indicate to my students the need to question the view that machines reduce the amount of work done. The thought experiment, similar to the thought experiment with ice walking, was unnecessary to perform anywhere except in the mind.

The Infinite Ramp Paradox

Imagine an infinitely long ramp; the angle that the ramp makes with the horizontal surface would be very small, infinitely small. What would be the force required to push the wheeled vehicle up this ramp? The answer would be next to zero of course and the wheeled vehicle would be raised one metre with no effort.

Students recognise raising a wheeled object 1 metre with no effort is implausible and ignore the consequence that an infinitely long ramp is not capable of raising an object in a finite amount of time. Gradually increasing the angle of this imaginary ramp, such that the ramp now makes a finite angle with the horizontal surface; I asked my students to determine the potential energy of the wheeled object at the top of each ramp. My students agreed that the potential energy would be the same, being dependent upon the height of the ramp and not the ramp's angle. The students saw the work done as co-varying with the length of the ramp and the force required in raising the wheeled vehicle. When re-examined, students were able to use the Infinite Ramp Paradox to ground their own understanding of the relationship between work and other simple machines such as pulley system machines; indicating the sophisticated view that machines increase work done because of the impact of friction on machines such as pulleys.

According to Lewis and Linn (2003), conceptual change occurs when instruction builds on intuitive beliefs. Students intuit a result, in the case of the infinite ramp, that they then translate into a novel situation. Lewis and Linn show how their students were unable to translate from a known to a novel situation. The students in Lewis and Linn's case maintained primitive erroneous views because of their lack of ability, specifically, wrapping a cold drink in foil to keep in cool instead of using the available Styrofoam. What is the origin of these intuitive conceptions? Again according to Lewis and Linn these intuitive concepts form in the same way that authentic dominant concepts are formed. "Intuitive conceptions result from students trying to generalize action, knowledge, observations, and on occasion, elements of causality."

The work of Lewis and Linn reinforces my previous claim that language has great impact on the formation of scientific misconceptions. As they state, "The imprecise way language is used in everyday life also contributes to the construction of intuitive conceptions that are inconsistent with scientific principles" (E. L. Lewis & Linn, 2003).

Students' clumsy use of language leads to problems. Teacher's use of non-student language to write and ask questions leads to inappropriate student responses. Students may give an adequate response if I word my questions after consideration of their inherent language difficulties. What I wanted from my students was robust understanding. I needed to beware of simply swapping fairies; substituting misguided student conceptions for equally misguided teacher-directed views, misguided, in the sense that the language difficulties caused the development of further misconceptions.

As was my custom I engaged my students in a dialogue. I recognised the need that I should heed Beck's (1993) advice when he says, "While schooling should as far as possible be dialogical, it should not be a mere pooling of ignorance" (p. 9). My ignorance of what my students believed they knew and my student's ignorance of what it was that I was requiring of them.

> *Morgan my eldest son who turned two last September demonstrates the capacity of very young children to engage in interpretation of observations and causation.*

Morgan claimed, "Darcy [his younger brother at 7 months] doesn't talk, he hasn't any teeth."

The voice comes from the mouth. Darcy has no teeth. Darcy cannot speak.

Darcy cannot speak because he has no teeth.

I asked Morgan, "Can chickens speak?" He replied, "No chickens don't speak, people speak.

Morgan had associated the power of speech with people. A reasonable action considering in his short life no other type of living thing had spoken to him.

For Morgan the only recognisable difference between people that spoke and his younger brother, who was unable to speak, was the absence of teeth. This example presents as one of Morgan's first steps toward development of his causal logic. Covariation of teeth and speech, the presentation of teeth prior to speech (priority) and contiguity certainly represented Humean causation but certainly not that causal logic espoused by Koslowski (1996) which must include a theoretical explanation. A theoretical framework for the hypothesis that the presence of teeth permitted speech was not available to this two-year old child. Nevertheless it was unmistakeable that Morgan had concluded appropriately, given the available information, and that his conclusion linked with the evidence. My journal shows the relevance of this observation for teaching grade 9 and 10 students.

Given the information he had at the time the statement was a reasonable one. His knowledge supported his belief. A kid in grade 9 or 10 may also hold similar views based upon their existing knowledge. Their conclusion would likewise, be rational. What do I find perplexing—aporia?

After this observation, I documented in my journal, I decided that I wished to devise a simple test of causation that could show my students were using the

Humean tripartite as a minimum but also, many would include, as is required by Koslowski, a theoretical justification for their conclusions.

The Black Box Experiment – a case study

My Black Box Experiment was inspired, partly by Erwin Schrödinger's famous thought experiment, and partly out of a need to remove the methodological complexity of the 'microgenic' strategy of Koslowski.

For my Black Box Experiment, I built a black electronic component box, the upper surface held three buttons marked 1, 2, and 3; additionally an orange light emitting diode (LED) was positioned on the upper surface adjacent the buttons. I could depress a concealed switch, at will, to cause the LED to become illuminated.

Students could speculate about the contents of the box and they also assumed that the buttons operated the light. It was through experimentation that my students would discover the function of the buttons.

I asked my students, "What evidence do you have that supports the conclusion you draw about what this black box can do?" I instructed students not to pick up the box—because I would reveal the lead for the teacher-operated concealed switch, the actual reason for the illumination of the LED. I told students, "I'll not answer any questions. You must ask all your questions of the box."

The protocol for my initial experiment was simple; no matter which button students pressed first I would activate the light. Every time my students pressed this first button and not the other two buttons I caused the light to illuminate.

In this first experiment students responded in three ways. Students concluded prematurely that the button they chose originally was the cause of the light operating and continued no further. Alternatively, some students would test the additional buttons, because they presented obvious additional choice options. Students concluded that the button first chosen operated the light. Thirdly, a few students, having checked alternative plausible options and the functioning of the first button repeatedly, conclude the first button pressed was the cause of the LED to illuminate.

I found that these three responses mirror my student's typical responses when examining other scientific experimental data. The third strategy was rarely utilised by my students, I conclude that this is the case because many students have the view that they have confirmation of their hypothesis and need proceed no further. This finding aligns with Stangroom's findings (2001) and also Wason's (1966) original test of logical thinking research. My students did not seek the disconfirming evidence. These same students quote human error as the most usual cause for them getting the 'wrong' data when examining experiments conducted in more familiar contexts.

The most common student response was to conclude from one piece of evidence alone. Below is a typical response for each of the three strategies B1 indicates button one and so on, L indicates the LED light was illuminated:

Strategy One

Test No.	B1	B2	B3	Light
1	✓			L

Student conclusion: Button 1 causes the light to operate

This subject (subject 1) assumed that, like switches in more familiar circumstances, a single button is the cause of illuminating the light. Once discovered subject 1 was comfortable concluding that they were lucky, but had discovered the correct button in their first experiment. Subject 1 failed to acknowledge other plausible control mechanisms. Some other subjects were not happy with concluding so quickly and sort to verify their conclusion by further experimentation.

Strategy Two

Test No.	B1	B2	B3	Light
1	✓			L
2		✓		
3			✓	
4	✓			L
5	✓			L
6	✓			L
7	✓			L
8	✓			L

Student conclusion: Button 1 causes the light to operate

The second subject concluded, plausibly, that button 1 is responsible for illumination without acknowledging other equally plausible causes (e.g. two button mode).

Strategy Three

Test No.	B1	B2	B3	Light
1	✓			L
2		✓		
3			✓	
4	✓			L
5	✓	✓		
6		✓	✓	
7	✓		✓	
8	✓	✓	✓	
9	✓			L
10	✓			L

Student conclusion: Button 1 alone causes the light to operate

Subject three repeated this pattern for more complex modes of light operation. When I employed a two button mode, as in the case below, subject three repeated a similar experimental methodology.

Experiment Two (Two Button Mode)

Test No.	B	B2	B3	Light
1	✓			
2		✓		
3			✓	
4	✓	✓		L
5	✓			
6		✓		
7			✓	
8	✓	✓		L
9	✓		✓	L
10		✓	✓	L
11		✓		
12	✓	✓	✓	
13	✓	✓		L
14		✓	✓	L
15	✓		✓	L

Student conclusion: Any two buttons cause the light to operate

My sophisticated Science students use a combination of confirming and disconfirming evidence to draw their conclusions. Students utilising strategy one stop experimenting when they make an observation that confirms their first hypothesis. William James would say a new opinion counts as true just in proportion as it gratifies the individual's desire to assimilate the novel in his experience to his beliefs in stock. Students utilising strategy 1 are unable to acknowledge other plausible causal agents, finding an observation that supports his belief; he does not validate his findings by attempting to refute his hypothesis—naïvely seeking only confirmation.

At the conclusion of experiment 2 subject three declared that, "any two buttons cause the light to come on." Tests 9-15 were designed by subject three to refute the hypothesis that buttons 1 and 2 caused the light, "to come on." The intention of subject three was to support the hypothesis, although as viewed by this researcher the experiments could be construed as disconfirming experiments which having failed; offered supporting evidence for subject three's hypothesis, formed initially after test 4. A conclusion formed after test 4 would be false because the light may illuminate when any two buttons are depressed.

Students utilising the second strategy acknowledge other plausible causal agents and require repeat tests to confirm their hypothesis, whilst students utilising the third strategy required multiple tests to confirm and disconfirm the Humean tripartite of causal agency: contiguity, priority and covariation.

The Mozart Effect – a case study

Subject 3, Andersen, always utilised strategy 3. Andersen was 16 and a member of a professional rock band that performed live at various venues in the local environment. He showed genuine interest in a dialogical approach to science inquiry and sort extension activities regularly.

When an opportunity arose to attend a meeting, I was unavailable for, at the Max Fry Hall to listen to American author Michael Kinasz's public lecture on, *The Mozart Effect*, Andersen gladly volunteered. Kinasz was a supporter of the belief that classical music, in particular Mozart's sonata for two pianos, could increase student intelligence. (Cf. Rauscher, Shaw, & Ky, 1993)

Kinasz reported that the Mozart Effect elicited the strongest increased intelligence response for spatial awareness but that the effect was short-lived, approximately ten minutes. Because I was unable to attend this meeting I asked Andersen, given his musical background and scientific interests, to attend the meeting and to critique the 'science' of Michael Kinasz as an assessment task.

The following day Andersen reported that he was unimpressed by the public lecture and declared Kinasz a, "crackpot." Kinasz had told Andersen of an experiment performed by a 16 year old American student showing the detrimental effect of rock music on learning. It was this claim of Kinasz's that had raised the ire of Andersen, an accomplished jazz percussionist.

The experiment reported by Kinasz utilised maze running of mice subjects to investigate learning failure. Kinasz's student randomly divided seventy two male mice into 3 groups of twenty four. He housed a control group under usual quiet laboratory conditions, to the test group he played rock music and the third group he played Mozart's piano concerto for two pianos. The mice exposed to rock music showed reduced learning and the Mozart mice showed an improvement, which led to Kinasz's speculation about and support for the so-called, Mozart Effect.

Andersen was critical of Kinasz's American student for failing to control music volume and unnecessarily controlling the gender of the mice subjects, Andersen felt that Kinasz was selective of experimental data, cherry-picking data that supported his 'concealed' hypothesis, that 'Rock music was harmful.' Andersen concluded that this second hypothesis was Kinasz's motivation for promoting the Mozart Effect. Kinasz used strategy 1; having assumed rock music causes harm, evidence was sort to confirm this assumption and alternative plausible explanations of the results of the American student's experiment were not entertained.

Applying his own logic, Andersen had refuted Kinasz's findings by rejecting the data as flawed due to the failure to control volume and proposed an additional experiment for Kinasz. Andersen instructed Kinasz to play mice Mozart at increasing volume, because Anderson's hypothesis that the negative learning response was being induced by noise volume alone. According to Andersen, this experiment would show no alteration to the response of the mice if Kinasz was correct and would refute Andersen's volume hypothesis. Andersen brought in his prior understanding that loud noise was a stressor and therefore linked this to the learning performance of the maze-running mice. Andersen stated, 'Learning would be inversely correlated with volume (dB)'.

Science teacher colleagues present at the meeting were equally unimpressed by Kinasz and were unreserved in their praise for Andersen. They amusingly reported that they were not interested in questioning Kinasz's methodology for the reason that they saw Kinasz as a person who was incapable of changing his mind, even after finding evidence that contradicted his proposition. Apparently, the silence after Andersen's suggestion lasted in excess of ten seconds and resulted in a, not-so-elegant, change of subject by Kinasz.

In 2010, in the journal *Intelligence,* Pietschnig, Voracek and Formann presented a metanalysis that once and for all disconfirmed the Mozart Effect. Their article entitled *Mozart Effect-Shmozart Effect* indicated, "…there is little evidence left for a specific, performance-enhancing Mozart effect" (Cf. Pietschnig, Voracek, & Formann, 2010, p. 314)

Galileo's Pendulum

The Black Box Experiments and the conversations with Andersen resulted in my development of an extended student inquiry into Galileo's own widely reported pendulum conclusions and Newton's Second Law. My journal states my planning.

> Find evidence to support or refute Newton's second law. In this case student intuition supports the view that force is proportional to acceleration and that the reciprocal of mass is proportional to acceleration. Find evidence to support or refute Galileo's pendulum conclusions. Students find it more difficult to act intuitively upon this inquiry because the students have no personal experiences that support intuitive acceptance. In the case of Galileo's conclusions student regularly support them in the face of evidence to the contrary. They base their support on the authority of Galileo. Mention of the resilience of student misconceptions has been mentioned elsewhere.
>
> Two examples of refusal to reject Galileo's conclusions are:
>
> Increasing amplitude increases period (T). As amplitude approaches zero degrees, T approaches that predicted by T = 2π√length/acceleration. Yet students always conclude that their results must be due to increasing human error instead of embracing the simple and reproducible data that indicates otherwise.

Increasing mass decreases T. As the mass of the bob increases, T approaches that predicted by T = 2π√length/acceleration; failing to correspond when bob mass decreases. Once again students conclude that [it] is they who must be wrong rather than the giant Galileo.

Certainly, Galileo lacked access to the precision timepieces of today to obtain data to acknowledge his error, much more likely is that Galileo recognised the influence of materials rubbing upon each other and chose to ignore these factors with the ever-present and oft-repeated physics caveat, 'neglecting friction'.

Galileo's technique, of comparing pendula bearing cork and lead bobs, showed little discrepancy. Employing these methods today, some students find similar responses and draw similar conclusion to Galileo. In his book, *Chaos,* James Gleick (1998) makes reference to the simple Galilean pendulum's lack of linearity. He writes in regard to the assumption of simplicity even when the likelihood of simplicity is low. The recognition by some of my students, Andersen amongst them, that the generalisation concerning periodicity of pendula does not hold true for all masses and all amplitudes, is a measure of those student's sophistication.

This is an example of Douglas Allchin's (2003) warning that the simplicity assumption is responsible for the development and persistence of student misconceptions.

Students examining Newton's second law quickly ascertain, using trolley truck and ticker timer, that force affects acceleration and that mass likewise affects acceleration. When students apply larger forces to a trolley truck (via falling fixed masses) the observed acceleration increases. After considerable practical inquiry students readily conclude that the relationship between force and acceleration is both linear and proportional and is congruent with their original view. It is usual for these same students to discover that the evident data disagrees with Newton's phenomenological equation, F = ma, and this is the moment when the wheels fall off my students' carts.

High school students appear incapable of naturally dealing with reciprocals and regard constructing graphs of reciprocals lacking in merit and necessity. Nevertheless, it is commonplace for students to report quickly that acceleration and mass are linked, after stacking trolley trucks (changing mass) and maintaining a constant applied force,. Again the data, necessarily, due to aging trolley truck bearings, fails to adhere to Newton's phenomenological prescription.

The scapegoat in formal student writing, for the incongruence of their inquiry's experimental data and the algebraic expression F = ma, is 'human error' which according to my students, wraps up and subsumes all manner of human failing from inattention to malfeasance. However, students readily accept the dubious quality of the bearings and it is not uncommon to find students aggressively spinning the trolley truck's wheels to make their choice of cart upon which they conduct their inquiry. It nevertheless is rare to find 16 year old students willing to engage in more than a cursory written exploration of the impact of friction on their experimental design, all students appear cognisant of the need to 'control' friction's impact on their experiments, demonstrated through spinning wheels. Students conclude verbally that if they had access to trolleys with high quality (frictionless) bearings the results would agree with Newton's phenomenological equation.

When encouraged, my students are able to recognise the balanced forces at work and can calculate the apparent rolling resistance of the entire apparatus, which includes the resistance experienced by ticker timer tape in its passage through the timer. My students appear to hold in abeyance their evidence that contradicts Newton's second law.

After the original prior knowledge quiz on mechanics, referred to earlier, I wrote 17 true/false questions to reflect a more appropriate language for students, the increase in the score was 14% (n = 114). Not a remarkable improvement given that students were contemporaneously inquiring into aspects of physics. I conclude the merit of the suggestion that language has a significant impact on what is referred to in the literature as student misconceptions to be not supported.

> *I finished rewriting the T/F quiz so that it would demonstrate students can learn if Q's are written in a sense they can understand from their alternative conceptions.*
>
> *Students need to find concrete or clear personal examples of these. Therefore only concrete understandings will yield answers. Anything that is abstract in nature and therefore not possible to find concrete examples the students won't, still, be able to answer the Q's.*
>
> *Are misconceptions based upon abstractions? An example given is comparing a garden hose water flow with the movement of a ball bearing off a ramp. They behave the same but in spite of some students seeing the familiar garden hose example they draw the motion of the reality different to the motion of the water.*

In the two examples of student and teacher experimentation both my students and I were testing hypotheses. I tested, clumsily, the view that language impacted on prior knowledge quizzes and my students tested the veracity of the claims of Newton and Galileo. In both instances the appearance is that both educator and student seek confirmation of hypotheses and tackle the claim validation naïvely. The limitation of my experimental claim, made clear by this evidence, and the need for further, more particular, experimental methodology for strengthening the claim is made explicit. This would include attempts at falsifying the claim.

In the case of student inquirers the lack of personal control over time and the limitations placed upon them prevented additional exploration of the work of Galileo and Newton and further experimentation. It is my contention that the students’ naïveté is a consequence of the classroom logistics rather than being a strictly personal quality. Deanna Kuhn (1989) would contend that the, “intuitive” scientist has not been given the freedom to demonstrate their own innate capacity.

When planning their scientific experiments my students’ attempt to find supportive evidence for their theories. The more appropriate way, according to Popper, is to design an experiment in an attempt to disprove their theory. If the theory stands against challenges, the theory is worthy of continued support. Good experimental design, for my planned student challenges, must include, inescapably, attempts at refutation. How could I support my students to make such attempts?

The ability to discern pseudo-science from warranted scientific claims is to be encouraged by science teachers. I encouraged my students to reject swiftly the fanciful notions of the scientifically illiterate, people like Michael Kinasz. Kinasz, a health professional, attempted to use the Mozart Effect to support his implication that rock music was summoning the devil. He used his authority as a medical professional to sway his audience. His two ideas, juxtaposed, seem reasonable to the uninitiated and scientifically illiterate. Yet the foundations of a scientific logic possessed by a sixteen year old science student were able to undermine pseudo-science and then illustrate what ostensibly amounts to little more than wishful thinking on the part of Kinasz. Whether or not Mozart’s Sonata for Two Pianos can lead to increased spatial awareness or not is irrelevant to the question of Satan arriving, carrying a guitar.

It is needless to illustrate the point that many people are willing, against all evidence to the contrary, to support beliefs that have no possibility of gaining scientific support. The world comes littered with examples. Such people are willing to swap fairies and chase other phantasms whilst the scientifically literate make progress by coordination of theory and evidence, examine causation and reason conclusively. Having attempted to falsify their own theories and failed, scientists are able to claim warrants for their theories of science.

My black box experiments continued with the view to answer this question recorded in my diary,

> *How can I demonstrate coincidental correlation as opposed to causal covariation? If I in science can't 'prove', does this mean that I cannot prove anything false and that the weight of evidence swings support to one of two alternatives? What does the student assert or deny; accept or reject; find true or false?*

When Leigh was first asked, "Do you make any assumptions about the black box?" He responded, "I think so." The first action of the black box experimenter requires a choice to eliminate and include some assumptions. Nothing except past experience compels the acceptance of the numbered buttons as causal.

Leigh reported the following methodological choices when he determined the black box's causal mechanism:

I made some assumptions. I then identified the variables that may have had some kind of influence. I looked to see if there may have been other alternatives. I tried a few alternatives. I looked for patterns in the experimental data. I tried to find a pattern. I formed some kind of 'best guess' hypothesis based on what I had noticed. I then looked to see if I could verify that as plausible, experimentally. Any time my hypothesis was contradicted by the evidence I rejected my original hypothesis. If the evidence I collected confirmed my original hypothesis I accepted the original hypothesis but also looked for additional verification experiments. I continued to look for confirmation; this then leads to my conclusion about the causal mechanism for the LED. I can call Leigh's method a scientific method of verification, he performed both confirmation and disconfirmation experiments.

Verification not Proof

My sophisticated students note that whilst one experiment may verify an explanation it may ‘in truth’ not indicate the causal mechanism. Fortunately, at about this time, Special Broadcasting Service (SBS) television screened a documentary on their *Cutting Edge* program about the faking, by Stanley Kubrick, of the Apollo 11 moon landing (Kubrick, 2003). My Black Box students examined the exploration of the evidence in relation to the programs claim.

The presentation date of this documentary was the first of April—the documentary caught many adult colleagues napping and they swallowed the con job. I found this circumstance most amusing. The fooling of my adult colleagues indicated a prevalence of illiteracy, of the logico-scientific kind, in an educated adult community. This was a similar situation to the white-tailed spider myth referred to earlier. The adults were convinced by rhetorical tricks such as the inclusion of the authority figures of Donald Rumsfeld, who appeared on news broadcasts regularly, Henry Kissinger adviser for National Security Affairs and Secretary of State under both President Gerald Ford and the infamous President Richard Nixon and, of course, the ironic and iconic Stanley Kubrick. In Kubrick’s film, *Dr Strangelove,* he has the President of the United States say, “You can’t fight in here. This is the war room.”

April Fools’ Day, being coincident with the television presentation, not ringing alarm bells in the minds of adult colleagues is a testament to the elaborate and sophisticated nature of the hoax. My students were more capable of examining the evidence in relation to the documentary’s claims rather than be swayed by the aforementioned, and to them, unheard of ‘authority’ figures. More contemporary authority figures may have garnered a comparable response from the youthful students in my care.

The SBS documentary presented opinions about the lighting, footprint depth and deaths of individuals involved in the program as well as interviews with the family of Stanley Kubrick, the documentary’s director.

The students, using the same technique they would use for the analysis of paradoxes, examined the documentary’s claims. Students examined the premises, the inferential links and the plausibility of the conclusions, together with the logical arguments supporting the director’s claims.

For a successful hoax, apparently all the duped viewer must do is accept the conclusion and work backwards through the logically consistent argument to a premise that has the capacity to lead via logically consistent arguments to the conclusion. To break out of this circular argument my students rejected the implausible assumptions that formed the basis of the documentary.

It was clear to my students, without any teacher interjection, that the probability of a hoax of this elaborate nature remaining secure with so many participants, for even the briefest amounts of time, was low. The conspiracy theorist’s attitude to implausibility, in contrast, is that highly improbable events are indicators of a conspiracy due to the complete absence of any evidence in support of their claims.

The prevalence of scientific misconceptions for such people would, most probably, be very high.

Chapter 12 – Myth Conceptions

> Romantic versions of scientists like Darwin, "…distort history and foster unwarranted stereotypes about the nature of science – all for the sake of telling an good story (Allchin, 2003).

Douglas Allchin (2003) warns about the temptations of myth-conceptions consequential with the mythic form. Hagiography, whiggism, gender bias, cultural ideologies and political motivations all contribute to the mischaracterisation referred to by Allchin. Allchin illustrates his concerns with the 'Peppered Moth of Bernard Kettlewell'.

The Peppered Moth

Standard science textbooks contain the expurgated version of the story of the peppered moth. They usually suggest that in 1848, prior to the publication of Charles Darwin's, *On the Origin of Species by Means of Natural Selection*; occasional mutant, melanic (black) variants of the Peppered Moth (*Biston betularia*) were found around Manchester, in the United Kingdom. By 1899, the majority, ninety nine percent, of captured moths were of the melanic or black form. This discovery coincided with the era of Darwin and Darwin's Theory of Natural Selection which proved to be the most lucid explanation for the transmutation of the Peppered Moth.

Allchin criticises science teachers' use of this illustration of natural selection because some science teachers fail to include the evidence of the 'insularia' presumably to simplify any ensuing discussion. Prior to 1848, melanic forms were unseen and all moths were essentially white with black speckles. As well as the melanic forms Kettlewell discovered in 1848, Kettlewell discovered intermediates between the 'white' and the melanic forms. Known as insularia, these intermediate types added complexity to any discussion of natural selection because they seemingly refuted Mendel's Law of Allele segregation. In the Birmingham and Dorset environments, Kettlewell noted that up to 40% of the moths trapped could be insularia.

Allchin criticises the failure of some teachers to include the insularia as an oversimplification of a complex situation that, "clouds student understanding". Allchin claims that the exclusion of the insularia gives students a false impression, making what is a complex situation appear very simple. I agree but for a slightly different reason.

I don't see this problem in black and white terms; with no shades of grey. The claim that Kettlewell may have glued moths to tree trunks, for photographic purposes, or that ornithologists' find *Biston betularia* on the underside of leaves adds condiment to the evidence rather than being the detractor suggested by Allchin. This example of species mutability illuminates natural selection and yet it is understandable that some teachers exclude discussion of the intermediate insularia for what I believe is a false justification; the simplicity premise. No doubt such teachers believe that their action will assist their students' concept attainment. Instead I believe the opposite is true.

With today's knowledge-literate student population the truth, in this instance glued moths or moth location, will out and necessarily lead to the equally false belief in the minds of my students that their science teacher is hiding something. This would be the basis for the awkward logic of a conspiracy theorist or creation-myth supporter such as Jonathan Wells, the author of *The Icons of Evolution* and the principle critic of Kettlewell's conclusions.

Allchin sees the simplistic view of omitting insularia in the examination of the peppered moth being part of the cause of many naïve rejections of natural selection. Reality doesn't mesh with their simplified conception of natural selection and therefore the contradiction, found after their discovery of the insularia, is grounds for rejecting natural selection.

Acceptance or rejection of evidence in a black and white way doesn't allow for the inclusion of multiple causal (gene) factors. Acceptance of the illustration of natural selection by peppered moths came easy to me. Prior to in-depth investigation of the peppered moth as an undergraduate, I had intuitive awareness of the existence of the insularia having grown up in Shorthorn cattle country. I was familiar with the roan, an animal with red hair interspersed with white hair giving the coat a paler red hue. In my youth, I thought these animals had pink hair. Co-dominance of alleles was causing this intermediate phenotype.

My initial difficulties, as an undergraduate, with Dobzhansky's genetics centred on the rejection of the misconception that genetic inheritance yielded an intermediate between the parents and that, in reality, allele segregation led to predictable ratios of phenotypes. Gene co-dominance evidenced also, by the Guinea Pigs I bred as a child, in the agouti coat type, allowed me to accommodate the roan without further investigation.

It was not until studying genetics as an undergraduate that I was able to revise my misconception; but doubtless was the value of learning naïvely of the genetic basis of inheritance. Similarly, what science teacher commences study of atomic theory with a quantum model when an orbital model suffices adequately to explain chemical reactions and bonding? People, with similar opinions to those expressed by Allchin, unnecessarily abandon Lord Kelvin's plum pudding model of the atom and Nagaoka's Saturnian model to the history books.

The Nature of Scientific Inquiry

These examples effectively illustrate the nature of scientific inquiry; new models emerging and displacing old models as evidence falsifies elements irretrievably through discovery of conceptual anomalies or scientific paradoxes.

It is the role of the science teacher to situate adequately the naïve conceptions as historical artefacts and this is where Allchin should be addressing his concerns. Good science teachers may inadvertently, yet effectively, teach out-dated and discredited theory if they include in their 'stories' historical elements without according significant time to insulate these ideas from currently accepted, warranted and necessarily complex, scientific claims.

Evidence will always contain elements of ambiguity. Some students found, in their attempt to support or refute Newton's Second Law, that they collected evidence both confirming and disconfirming and ostensibly, almost inevitably, the students yielded to authority. What rhetoric, what experience, allows students to examine ambiguous data in such a way that it does not confound their intellect? The opportunity exists in the exploration of semantic, logical and scientific paradoxes.

According to Allchin, "Simplification may seem inevitable in education. Simple concepts, even if flawed by overgeneralisation, seem essential foundations." (Allchin, 2003, p. 345) Allchin's states his position ironically as, "In my view, educators should reconsider the power and impact of these narratives" (Allchin, 2003, p. 344).

He re-presents that overgeneralised and simplistic narratives appear to be foundational yet paradoxically have enormous capacity to positively impact student learning. Similarly, I find that the view of the foundational nature of simplistic or naïve conceptions to be valid. How then does one accommodate the clearly contradictory positions?

I believe it is possible to view the contradictions of science or education paradoxically. It is my contention that many of the profound, and as Sainsbury describes, "cataclysmic" paradoxes are essentially irresolvable and offer an arena for engagement in the rhetoric and dialogue of paradox. The contradictions and paradoxes of science and science education similarly offer an arena for discourse. Welch (1980) states, "…paradoxes are uniquely effective in addressing specific deficiencies in understanding." What is essential is that the participants recognise the contradiction in the first instance and this necessarily implicates the science teacher.

The warnings of Allchin can be translated into a set of principles of sophisticated scepticism. I suggest to teacher they should: suspect simplicity, be wary of vignettes, embrace complexity, embrace controversy, discard romanticised images, don't inflate genius, mix celebration with critique, scrutinise retrospective science, revive science in the making, explain error without excusing it and respect historical context.

It was Kieran Egan (1997) in his book, *The Educated Mind*, that suggested the significant contribution of the, ‘mythic tool’ in education. Allchin does not damn its inclusion; he simply espouses the mythic tool’s capacity or power to delude an unsophisticated audience.

When I told my two and half year old son that his ice-cream was two colours, white and pink, I used an oversimplification, the statement was necessarily misleading. Morgan was too immature to make sense of the concept that black and white are not, in a technical sense, colours. Yet it was not an unreasonable starting point for a child who was beginning to associate words with the visual perception of colour.

I formed the opinion that all student misconceptions were a consequence of poor assessment of evidence or poor recognition of the nature of evidence in science. The following example makes my point.

What evidence exists to support the statement that an object travelling at constant speed through a turn experiences acceleration? Students with knowledge of force and motion often persist with the naïve view that the word acceleration implies change in speed. They do so logically, using their vernacular sense of the term ‘to accelerate’. For my students ‘acceleration’ initially pertains only to increasing speed.

Many students do well by accepting, quickly, the notion that acceleration occurs when the speed increases *or* decreases, however, it appears difficult for many to grasp constant circular motion as a form of acceleration. The supporting evidence relates to the Law of Inertia and therefore indirectly to this form of acceleration. If a student persists with believing, falsely, in the need for an object to have a force applied to maintain motion it is unlikely that they will accept acceleration when speed is constant.

I thought of ways to assist my students to change their understanding of constant circular motion and acceleration. I wrote in my diary:

> *An object that does not change speed yet turns, experiences acceleration yet students so much relate acceleration to changing velocity amplitude and conclude a = $0m/s^2$. From first principles: What does a force do? (All students answer this correctly and require little effort to conform to the scientific claims) Force causes acceleration, change of direction and distortion. What causes the object, engaged in circular motion to change direction? A force. If a force is applied does the object not accelerate because Newton's Second Law would apply?*

In this example of a paradox, an apparent contradiction, perceived by the students; force causes acceleration, force causes change of direction yet here was a situation perceived by the students in which a force both did and did not cause acceleration. How was this to be reconciled? My students eventually allowed the premise that a force causes the change in direction to hold priority and therefore they chose to accept what, at first, appeared to them to be a contradiction.

Bertrand Russell's philosophical writings as well as his already mentioned paradoxes; Russell's Set Paradox and The Barber Paradox, were providing useful strategies for my students to create understanding, such as in the case just illustrated. Russell's cynicism of the role of pedagogues and education bemuses me, especially when Russell had found and thereby described paradoxes so beautifully.

James Gleick's book, *Chaos* provided an interesting insight into the simplicity assumption exposed earlier in this chapter. I had originally read *Chaos* because of Gleick's comment pertaining to the Galilean Pendulum's lack of linearity. Gleick's writing referred to scientists' assumption of simplicity even when the probability of simplicity was low. The simplicity assumption was a characteristic of my own students and the likelihood is that this was a deeply embedded human trait, as epitomised by the razor of William of Ockham.

Developing Sophistication

Teachers sometimes ignore or reject complexity. They admire or longed for simplicity as in the cases of Kettlewell's moths or the pendulum of Galileo. It was easier for my students to reject the simplicity of their pendula after examining their experimental evidence concerning the effect of amplitude and mass.

My students were able to place caveats on the claims they made with respect to Galileo's pendula and they transferred their sophistication to their examination of the case of the Peppered Moth. My students' rejection of the simplistic model, that which excluded the Insularia, was possible but unfortunately it reinforced the misconception that intermediate forms were examples of 'phenotypic blending'. Allele segregation was too complex for my students to grasp. To contradict the notion of phenotypic blending I devised a practical experiment that would show allele segregation.

Pea seed stock were accessed through the Dean of Science and Engineering, Professor James Reid and Dr Jim Weller at the University of Tasmania. The genetic stock helped in two ways; the peas illustrated the transmission of recessive phenotypes and also helped dampen down the tendency of students to conclude that; for example, a dwarf pea plant crossed with a tall pea plant would produce a medium-sized pea plant; what I previously referred to as 'phenotypic blending'. Much later, I would use a variety of mouse phenotypes for breeding experiments in a similar way. I asked my students to breed mice with tail phenotypes 'tailless' (recessive) and 'tailed' (wild), as a means to demonstrate phenotypic bleeding for the misconception that it was.

Mendel's Peas

I originally use parental lines of *Pisum sativum*, Line 107 (L107) and Line 117 (L117) for student genetic studies. The characteristics of each line provide a dramatic demonstration of the falseness of the student misconception I have cast as phenotypic blending. The characteristic of each line is indicated in table 3 following.

L117	L107
Round Seed (R)	Wrinkled Seed (r)
Yellow Cotyledons (I)	Green Cotyledons (i)
Long Stem (Le)	Short Stem (le)
Tendrils on Leaves (Tl)	No Tendrils on Leaves (tl)
Leaves and Tendrils (Af)	Tendrils for Leaves (af)
Red Flowers (A)	White Flowers (a)

Table 3 - Characteristics of L107 and L117

The first filial generation (F1) brings in to stark contrast the visual difference between the parents. Students expect that the characteristics expressed by the offspring should be intermediate between the two parents, that is if they believe in phenotypic blending. What the students discover is that all members of the F1 generation, with no exception, are identical to L117 i.e. all plants are tall with regularly formed leaves and tendrils. L107 is a very short plant with no leaves or tendrils. The F1 generation looks like what my students believe pea plants should look like. Students then, and with ease, reject the simplistic phenotypic blending hypothesis and although a knowledge void is created by the absence of a suitable explanation for observed results of the hybrid, some students are able to comprehend the role of chromosomes as the means for transmission of genetic information. Some students could explain the absence of recessive phenotypes in the F1 generation and their re-emergence in the second filial generation (F2) by invoking the genetics brought to us by Theodosius Dobzhansky. Dobzhansky’s (1936) book *Genetics and the Origin of Species* was the first attempt at a chromosomal explanation of the heredity concept known as Mendel’s First Law of Allele Segregation.

It was possible after this experience for my students to reflect on the existence of the insularia and transcend the simplistic model, laying down Allchin's concerns about oversimplification and embracing complexity.

An ABC documentary about the Nina Simone song 'Strange Fruit' called the song a triumph of over-simplification.

Billie Holliday derived the song 'Strange Fruit', in 1945, from a poem written by a white Jewish schoolteacher, a poem written in response to the lynching murder of black Americans. The American Anthropologist and dancer Pearl Primus had previously created a dance called 'Strange Fruit' that provided some of the motivation for Billie Holliday's song.

I felt the song possessed enormous power thereby warning me of the unintended consequences of unnecessary complexification. It is indeed preferable to choose simplicity over complexity provided that the simple models do not corrupt, creating knock-on effects, as was the case for my students in both the pendulum and moth examples.

I regard oversimplification as damaging simplification and overcomplexification as damaging complexification; so when the documentary referred to 'Strange Fruit' as a "triumph of oversimplification" I was concerned. Perhaps I might view their comment ironically because of what I perceive as the song's evident complexity.

My efforts to resolve my dispute with the Department of Education (D.O.E.), over the provision of study leave, gave me an opportunity to apply what I understood about argumentation and logic, from my outcome it appears that I had learnt a great deal about both. Although the State Service regulations provided for study leave for teachers, the D.O.E. only gave non-teaching staff and those seconded to administration the opportunity to take it. This was an injustice that I needed to fight. After a year or so of logical analysis the matter went to arbitration after I filed a discrimination complaint. The Commissioner of Review ordered the D.O.E. to grant me paid study leave every year until the completion of my doctorate. That would have been nice. I resigned from the

Department in 2008 to take up a position at a private school with a similar stance on the notion of study leave for academics. My school has graciously allowed me to take study leave to come to Chartres, in France, to put the finishing touches on my thesis; albeit without pay.

Whilst we awaited the growth of our pea plants, I discussed further work on the inheritance of recessive human traits rather than traits of mice or peas with my grade 10 students in the form of an academic controversy. I fabricated a statement about the compulsory termination of foetuses with cystic fibrosis (CF). My students, by this stage, understood the inheritance of recessive conditions such as CF and knew that as a strategy to eradicate CF termination would be an abject failure. A statement indicating CF gene concealment by carriers would be an appropriate response to students who supported the fictitious policy. Most of my students chose not to use rational-logical justifications to construct their argument. Instead they attacked the policy by using, 'right-to-life' ethical arguments about the fairness of compulsory termination, both from the perspective of the unborn embryo and the perspective of parents. The ethical argument was certainly worth exploring, but was obsolete and nullified in the face of rational-logical rejection, which may have developed if students, instead, focussed on the theoretical justification for the policy—the underlying assumptions. I felt frustrated with the failure of my students to utilise the logic they developed in other contexts. I conclude this occurred as a consequence of the emotional content of the fabricated statement concerning compulsory termination.

My frustration with my students' avoidance of rational arguments was made even more acute when, as is regularly the case, I am required to attend compulsory staff meetings, referred to as *forums* in defiance of the Oxford English Dictionary definition. An Education Department representative spoke about the inclusion policy of the D.O.E. that had emerged from the, 'Atelier Report'. My frustration is evident in my journal entry of the 6th of May.

Forum tonight, once again taken up with PD type material. Re – Inclusion Policy. Again an emotive argument-based spiel with music and photographs of the poor 'retards' [the implication of the presentation], fuck how can they do it to us yet again. The emotive argument was very insulting to people with disabilities. Using emotion rather than rational logic suggests there isn't a rational logical reason for inclusion. That is insulting. It was insulting to me in that it treated me as a manipulable individual.

Acknowledge that having a category 'A' included student increases a teacher's workload. Usually it is unsupported; the staffs as a consequence don't choose to work with included students.

What are the pros and cons of inclusion, as an included student, a student, a teacher, a support teacher, an administrator, a department, a state government and a federal government? [I additionally include: a parent, a community]

I proposed the following parable for my colleagues in response to my feelings of frustration.

The Disappearing Man

A man leaps in the air in a joyous moment, having just remembered something he had forgotten. As he falls to earth he recalls Newton's Gravitational Law:

$$F = Gm_{earth}m_{man}/r^2,$$

Then he remembers Newton's Second Law — being particularly fond of Newton:

$$F = m_{man}a$$

The m_{man} thinks to himself:

$$\text{If } F = Gm_{earth}m_{man}/r^2$$

And:

$$F = m_{man}a$$

Then:

$$Gm_{earth}m_{man} \div r^2 = m_{man}a$$

So, as the man fell to earth he accelerated in the constant fashion ascribed to him by Galileo such that his acceleration ‘a’ was:

$$a = Gm_{earth}m_{man}/r^2m_{man}$$

The man seeing himself both numerator and denominator did the just mathematical thing and cancelled himself:

$$a = Gm_{earth}\cancel{m_{man}}/r^2\cancel{m_{man}}$$

Just in time before he hit the ground.

When my Principal, in my mind a daughter of Zeus and Mnemosyne (from the Greek *mnēmē* meaning memory), retired at the end of 2003, I presented her with my painting of the parable; the chalk-line silhouette of a man falling head-long with a back-drop of the text.

I was ironically, disappearing from her life.

I think that being able to construct a rational argument should take priority over all other forms of rhetoric, yet, I continued to be interested in what was going on in the minds of my students who thought about science in most unusual ways.

Chapter 13 – Writing Would Be Easy but the Words Just Get In the Way

The title of this chapter is one stolen from an Australian drama, 'The Secret Life of Us'. The lead character and sometimes narrator, comments on his writer's block and in so doing makes it possible to move forward. The title is an apt description of the feelings of my students attempting to write a theoretically constrained explanation of their experimental observations of, for example, 'The Inclined Plane' experiment.

I noticed something familiar in the irreverent writings of Paul Feyerabend. It was Feyerabend who encouraged a rejection of the post-modern relativist's, 'loss of certainty' as opposed to the positivist's, 'lure' that pervades much of what is recognised with 20th Century philosophy. I like Feyerabend's affirmation of my sentiment in an entirely Jamesian way.

In *Killing Time*, Paul Feyerabend (1995) justifies his motivation for writing *Against Method*,

> One of my motives for writing Against Method was to free people from the tyranny of philosophical obfuscators and abstract concepts such as "truth," "reality," or "objectivity," which narrow people's vision and ways of being in the world. Formulating what I thought were my own attitude and convictions, I unfortunately ended up by introducing concepts of similar rigidity, such as "democracy," "tradition," or "relative truth" (p. 179).

Feyerabend was mystified to find that what he set out to avoid had, by the very nature of the descriptive language, been his undoing. He puts it,

> Now that I am aware of it, I wonder how it happened. The urge to explain one's own ideas, not simply, not in a story, but by means of a "systematic account," is powerful indeed, a struggle I was all-too-familiar with, how else can one explain how an outstanding theatrical director such as Herbert Blau—an artist capable of making opaque roles and plays clear to actors and audiences—can have produced a

> treatise on the theatre that contains incomprehensible statements and plain nonsense?

Feyerabend claims I and others are enticed by, "…the wish to be great, profound, and philosophical." (Feyerabend, 1995) Feyerabend contrasts an author's capacity to demonstrate understanding with the moniker, 'deep thinker'.

> Writing in a simple style that general readers can understand is not the same thing as being superficial. I urge all writers who want to inform their fellow citizens to stay away from philosophy, or at least to stop being intimidated and influenced by obfuscators such as Derrida and, instead, to read Schopenhauer or Kant's popular essays (p. 180).

Feyerabend's mistake is that by being plain he is demonstrably not thinking deeply. It is Feyerabend who encourages me to use anecdote, story and sentiment to allow my thesis wide readership.

> "Scholarly writing, by necessity, contains reasoned argumentation but does not require the absence of anecdote, story, sentiment, even pathos. The twentieth Century saw the professionalisation of philosophy into academia, with the exception of Santayana and Sartre, producing writing, not for general consumption by the men and women intellectuals but by other philosophers and this fact led to the impenetrable language that guards philosophical inquiry."

I would think that Wittgenstein would be horrified. The role he saw for philosophy is simple.

> Philosophy aims at the logical clarification of thoughts. Philosophy is not a body of doctrine but an activity. A philosophical work consists essentially of elucidations. Philosophy does not result in 'philosophical propositions', but rather in the clarification of propositions. Without philosophy thoughts are, as it were, cloudy and indistinct: its task is to make them clear and to give them sharp boundaries. (Wittgenstein, 2004, pp. 29-30)

I feel that I have attempted to honour Wittgenstein's sentiment with my thesis. A difficulty may yet exist for my readers who believe this thesis is about the embedded paradoxes rather than about science teaching utilising paradoxes.

There is no challenge for me to the thought that many of the paradoxes exposed are labyrinthine in their difficulty.

Authentic Learning – a euphemism

Making your own meaning of knowledge is problematic in the absence of the reasoned judgement and experience. To illustrate this point I refer to an experiment of the Department of Education in response to a paucity of experienced and well-trained teachers of science; teachers that possess not only knowledge of the concepts of science but also the methods of inquiry employed by scientists. Under the guise of 'authentic learning', generally a euphemism for whim-driven, student-directed study, students embarked on a theme-focussed unit guided by an untrained (in science) teacher, whom in spite of what seemed to me obvious short-comings, had claimed unbridled success in teaching this particular unit of science.

My Principal asked the Grade 8 students involved in the experiment to attend a 'student-free' day, where the majority of students are off-campus, to talk about their 'authentic' learning experience.

The untrained teacher, Mary, talked about how well she thought that she was teaching out of area; including science. I asked 3 groups of students to tell the teachers present what they had learned about osmosis and diffusion. The two central concepts, according to my own science knowledge, that were essential for any person studying the digestion/chemistry unit the students tackled. Not one student could begin to talk about these two most important concepts, although one student said, "give me a week and I'll find out". The worry I see is that the non-specialist teacher is unable to see the absent concepts. Mary said she would call on the experts when she needed to but perceived no need because of her own naivety.

This problem stems from the philosophical stance of people advocating the 'authentic learning' approach. Authentic learning advocates want situated learning, and they view knowledge from a positivists' perspective. These advocates see knowledge as bricks, picked up and carried forward. They desire students make their own meaning of the ideas, which is commendable, however they reject the value of the history of development of the ideas. Their strategy amounts to the pooling of ignorance referred to earlier by Beck (1993) and Ortega y Gasset.

Mary had a blend of logical positivist (logical empiricist) science, as 'bricks of knowledge' and the post-modern (relativist) science as 'knowledge created by the individual'. The authentic learning experiment was, in my opinion, a doomed failure because of the problem of commencing their actions from their own false assumptions about the nature of science. Unaware of basic human physiology and chemistry, students were being effectively taught, rather ironically, by a passionate, convincing, self-assured and yet utterly ignorant teacher. The pooling of ignorance that results from such an experiment should not be acceptable to an education system, whose role I see is to generate students in the mould cast by Kieran Egan (1997). Students should possess a,

> …sceptical, philosophical, informed mind that energetically inquires into the nature and meaning of things, that is unsatisfied by conventional answers, that repudiates belief in whatever cannot be adequately supported by good arguments or evidence, and that embodies the good-humored corrosive of Socratic irony" (p. 18).

The experiment made my role as the students' teacher in the following year doubly difficult because my students' lacked knowledge and appreciation of key concepts.

Both Feyerabend and Wittgenstein propound the need for clarity. Feyerabend wants clarity for the intellectual and Wittgenstein for philosophers. It is quite paradoxical that Wittgenstein attempts his own 'clarification' in his *Tractatus* because here Wittgenstein denies metaphysics by invoking metaphysics.

My professional objective written in my journal states:

> *Educate myself, my students, and my learning community. Although I suspect that this simple statement may not meet the*

expectations of a committee; a simple truth lies in this simple statement.

Students' Understanding of Evidence in Science

Since beginning my doctoral studies I have taken a course of exploration including; structuring a curriculum for senior science students aimed at tapping into students' understanding of the nature of evidence in science, interviews with students regarding their interpretation of the nature of evidence in science, thoroughly exploring recent and historical literature concerning evidence and student alternative conceptions; and exploring modes of qualitative inquiry including narrative modes.

After reading Vanessa Barker's report prepared for the Royal Society of Chemistry called, 'Beyond Appearances: Students' misconceptions about basic chemical ideas' (Barker, 2003), I structured a unit for grade 10 students centred on the simple concepts of atom, element, molecule, compound, gas, liquid, solid. The purpose of this unit was to develop complex concepts: the particle theory of matter and the kinetic theory of heat. My catch-cry, used in response to student assertions was, "What evidence do you have for the belief that [insert student assertion]".

Over 25 hours, students investigated only three regularly experienced chemical reactions: the reaction of calcium carbonate with hydrochloric acid, lead nitrate's reaction with potassium iodide and the combustion of magnesium in air. I asked my students to pay particular attention to measuring the mass of each reactant and product. It was essential that students already possessed the view that matter was made of tiny particles and that these particles could diffuse when in solution.

It is still strange to me to discover students unfamiliar with the words soluble, insoluble and solution in grade 10. These same students have little trouble with dissolve, evaporate and crystallise given the other mainstream activity, usually undertaken in grade 7, of producing crystals from saturated solutions of salts such as copper sulphate.

After earlier, formal examination of the consequence of force acting on a body, the prior learning in grade 10, students are able to invoke logically, particle and kinetic theories of matter. The theories are necessary to explain the migration of particles of lead and nitrate ions toward particles of potassium and iodide ions. Solid crystals of soluble lead nitrate and soluble potassium iodide were placed on opposite sides in a basin of still water, minutes later the formation of insoluble, yellow, lead iodide appears as if by magic. As tempting as it may be for some of the students to suggest supernatural magical explanations there is little need given the lucidity with which all students grasp particle and kinetic theory within the context of this reaction. I demonstrated an analogy for the electrostatic bond between the cation and anion (in the case of the soluble salts) by rubbing a balloon on a student's head and sticking it to the ceiling.

The strength of the electrostatic bond accounts for the variation in solubility of different salts but opens a 'can-o-worms' for a few students who indicate two paradoxical observations; the lack of repulsion of the protons occupying the nucleus of the atoms and the lack of mutual attraction of the protons of the nucleus and the electrons in orbit around the nucleus. Superglue and a couple of repelling magnets dispensed with repulsion by indicating the presence of a stronger attraction force. No analogy was able to dismiss for my students the failure of the electrons to descend and crash into the nucleus although an orbital model came closest. Still, my students were unsure why it is that the moon fails to coming crashing down. Students were able to use If Then arguments developed by studying paradoxes to explain the formation of yellow lead iodide in the centre of a basin.

The combustion of magnesium allowed the revisitation and examination of Phlogiston Theory (T. S. Kuhn, 1962; University, 1997) that was introduced in grade 9 via the study of Joseph Priestley's role in the development of the concept of photosynthesis. Students naturally reject the absurd claim that matter like phlogiston possesses negative mass; a logically deduced consequence of Phlogiston Theory. Matter having mass, according to students, appears *a priori* knowledge; the *a priori* knowledge added to the weight of claims by many that Priestley lacked a scientist's, 'preternatural abhorrence of contradiction', embedded within their own explanations of phenomena and brought forth as logically deduced consequences.

Their paradoxical observation arising from this experiment briefly confounded my students. The paradoxical observation was the increase in mass of the magnesium after combustion. The everyday example evoked by students is the loss of mass by the combustion of 10 tonnes or more of firewood, burnt during the preceding winter months that leave an ash residue of only a kilogram or so. Given their *a priori* knowledge, 'matter possesses mass' students argue that the magnesium has gained mass because it has gained matter (atoms) and the likely candidate is oxygen because of their declared knowledge that oxygen is required for the combustion of matter. Measurement of the mass of reactants and products and the introduction of the mole concept confirmed the predictability of the change of mass that occurred when burning magnesium. Further combustion experiments of larger and smaller pieces of magnesium demonstrated a consistent ratio of magnesium to the increase in mass observed.

The third reaction performed by my students was the combination of a carbonate with an acid. My students confirmed for themselves that the visible loss of matter in the form of carbon dioxide (CO_2) gas bubbles corresponds to the measured loss of mass during the reaction. My students explained to me that the mass of carbonate used acted as a predictor of the mass of CO_2 lost. The concept of a mole reinforced for my students the predictability of the observed change in mass.

This course of study allowed me to examine my student's ability to reason formally about the concepts covered within high school chemistry curriculum, utilising cognitive tools developed by studying paradoxes. Within this arena of discourse it was uncommon for a student, having engaged with the language of chemistry and the language of logic, to fail to utilise adequately either kinetic theory and or particle theory to explain phenomena. Additionally, aspects of previously encountered atomic theory was used to explain, 'side-bar' issues such as ionic bonding and the variability in the solubility of the soluble and insoluble salts encountered.

Symmetry

Whilst occupied with chemistry my two and a half year old son was delighting in stacking blocks. The primary-coloured wooden kind and the ever-present Lego were his favourites. Morgan always stacked blocks symmetrically and I was interested to see how he would respond when I arranged dissimilar stacks of blocks in front of him (see figure 4). The following figure is an example I noted down in my journal. I was interested in Morgan's response because his initial reaction was to make each of the stacks equal in height. Having made them equivalent in height he acknowledged that the bases were dissimilar and 'corrected' this feature. I point out to my reader there was no need for him to be cajoled to play with the blocks, he was merely having fun and following his instinct for symmetry. Modesty alone prevents me from wallowing in fatherly pride and including a picture of a 500-piece Lego masterpiece to illustrate Morgan's particular propensity for mirror symmetry.

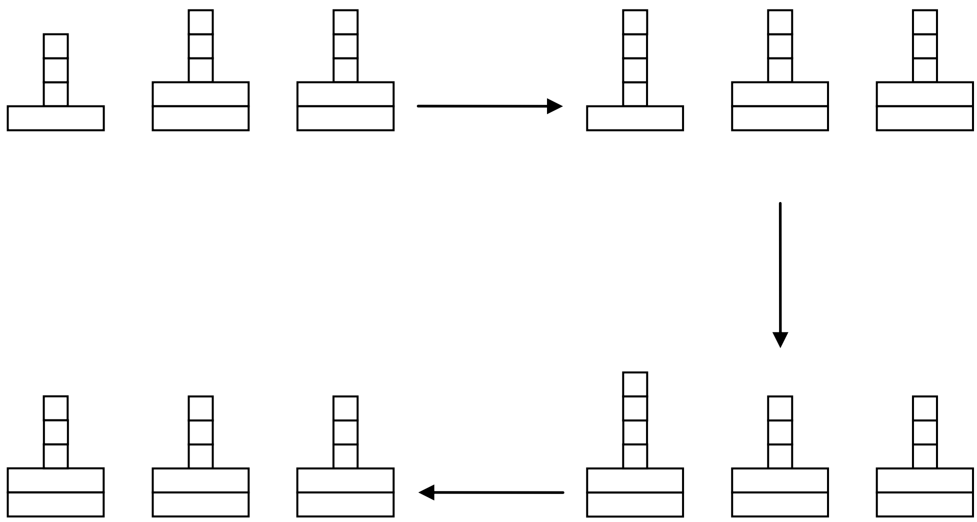

Figure 2 - Block Stacking Symmetry Transformation

Our theories of science, such as those pertaining to the chemistry just illuminated, match Morgan's block stacking in certain ways, in that my students seek symmetry between their declarative knowledge and their observations; and my students have a theoretical foundation (e.g. particle theory) to shape the direction of their changing understandings, whilst my son is disturbed by the asymmetry into making adjustments. What appears as *ad hoc* adjustment, on the part of Morgan and the grade 10 students may be methodical application of strategy. My own training allowed me to see only my students mismatch of theory and evidence where it occurred. I was tempted to conclude that students failed to understand what I was teaching whereas it may be that my students had not yet finished adjusting the 'shape' of their scientific notions and more time was required for this to occur.

My journal notes indicate that I was sensing that if Morgan could apply a consistent methodology that initially moved him away from his final structure before the final necessary adjustments for his symmetry then maybe some of my students in their own initial attempts at developing understanding were applying sound logic even though it appeared that at first they were moving away from what I saw as the correct representation of phenomena.

> *So therefore does this mean… children may demonstrate naïve modes of reasoning that are expressed to a greater degree of sophistication in adulthood. But, could it be just possible that the adult version displays no new attributes at all merely increased sophistication[complexity] of the same basic 'human' habits. Would it mean therefore that it is possible to view children to ascertain the fundamental rules[patterns] whereby an adult reasons. Could it mean that adolescence presents opportunity to examine 'the missing link' between naïve and sophisticated scientific reasoning based upon 'sameness' and 'not sameness'? Difference is, in fact, not recognised as a set, really 'not sameness' is somehow a subset of sameness. This may be the foundation of Binary Structuring (B.S.).*
>
> *B.S. is built for sameness and matching what about sameness is pleasing. Evolutionary Psychology would suggest that recognising self is an essential attribute to survival. This is*

essentially therefore a primitive instinct. We must therefore resist this primitive instinct to make progress, as our present view is an artificial construct of our fears, instinctive or otherwise.

I was sorting through the difference between what could be demonstrably known to be true and what was merely supposition.

There is a paradox embedded in what I am trying to do. What sort of evidence do I mean? Empirical evidence? Is there another sort? The nature of rational evidence. Is there intuitive evidence? "Something just made sense." Students have said things like this about evidence. Some things like continental drift are knowable. Other things like the particulate nature of matter cannot be absolutely known. The student who fails to make sense of the data aimed at undermining their misconception. What is the reason? Can paradox exploration help? Is it possible that those eventually changing to the 'normal' science version of events have really been brainwashed?

I am trying to encourage deep thinking about aspects of science. There is, I think, no disputing that teaching the nature of science is a valuable tool for encouraging deep thinking within the science context. Can the study of paradoxes also encourage deep thinking? Engagement with conceptually difficult material is the most challenging aspect of teaching. Are there students that could not approach science in this way? I do have success with students of high intellect therefore what I do is valuable. Am I fooling myself to think that what I do could be equally valuable for those not so bright students? Do I encourage the moderate student? Do I switch on or off those moderate students?

All Ravens are Black. Where does this logic exist in science? All objects (of thought) possess a polarised quality. The ravens are one such class of objects. Polemics act as provocation for action.

Ravens are a class of objects and are a set by nature of the concept 'species', yet species are not immutable. Hempel wrote this [The Paradox of the Ravens] after Dobzhansky's 1935 essay "Critique of the Species Concept in Biology."

All ravens are ravens. Everything that isn't a raven is not a raven. All ravens are ravens if and only if they are ravens. Ravens are black if and only if ravens are black. If ravens are black then all ravens are black. All ravens are black. Bah Humbug!

Ted's Evolution

Ted's Evolution, screened on ABC television presented a great opportunity to see Kuhn's theory of science in action. The wider scientific community roundly rejects Dr Ted Steele's Neo-Lamarckian views. Included in this documentary were stories about: Karl Popper, Sir Peter Medawar and Trofim Lysenko. Medawar wrote an interesting essay on the limits of science which appealed to me when I was younger.

At the same time as the ABC aired *Ted's Evolution*, a native Ukrainian was acting as a relief teacher at my school. She was able to clarify, first hand, the impact that Lysenko had on the learning of genetics and science at his height of power in the Soviet Union. Lysenko banned the study of genetics in the Soviet Union. Scientific genetics competed with his pseudoscientific views about species mutability. Both Lysenko and Ted Steele expressed Neo-Lamarckian views. Thomas Kuhn's competing paradigms theory explains why Steele's theory struggled to find traction. Lysenko, on the other hand, was politically motivated what he did was not science. All evidence indicated that his claims to know anything about the transformation of grain were false.

Popper had moved to the London School of Economics in 1949 to become the Professor of Logic and Scientific Method in spite of claiming the non-existence of a scientific method. As he says, there are some simple rules of thumb [heuristics] and they are quite useful.

Originally, I had intended to show my grade 10 students the documentary, *Ted's Evolution* but found that it contained information that was comprehensible only when viewed by those with extensive knowledge of evolution. Instead it got me thinking more about the patterns that had emerged in the work that I was undertaking with my class.

I had used physics and the study of force and motion as a means to explore the generalised scientific statement, biology to explore scientific fallibility and chemistry to explore falsification as the requisite for our scientific claims. Steele's theory had provided me with the thought that I was causing the students in my care to be 'swapping fairies' expressed in chapter 11 where I believed some of my students were simply swapping their non-scientific conceptions for any other conception, false or not, on the basis of my authority as their science teacher. The students, whilst studying genetics, had exchanged some of their own primitive views (misconceptions) based on ignorance with the accepted scientific views but the way they had acquired them had been similar to the way they had accepted the tooth-fairy. When my student, Taylor, stated that, a "the white moth breeding with a black moth produced a new species of moth…" swapping fairy was what appeared to be happening.

> *New species evolved through natural selection and within species change. The future species and the current species are the same species. Taken out of time attempts to breed would fail therefore suggesting different species. Even though they are the same there is a need to express them as different. The missing link is a missing link, it will never be found. The two forms of the one species are connected by a continuum; the definition of 'species' needs to change, so that it includes all temporalities.*

My own view about the conflicted definition of species expressed in my chapter 7 titled, The Left-handed Frog, arose from Taylor's flawed view that species change occurs when there is any phenotypic difference exhibited in the offspring. That and *Ted's Evolution*, coalesced into an hypothesis that was very much dictated by my ever-present struggle with Hempel's Ravens.

My student Keren, when she asked, “Are you always so logical”, showed the view that my logic has the capacity to mislead and misdirect? Her comment to me occurred after I had made a comment to her about body language and engagement in group work. As an illustration I had looked quickly around the room for an example. A table of six students engaged in an academic controversy about the use and promulgation of transgenic technology showed five students with their attention focussed on a central point, indicating engagement. Another student Nate, was turned at a right-angle to the table so that his back was to two of the five other students. When I asked Keren what was going on there, she said, she believed Nate was not engaged in the task.

I used this as an opportunity to indicate the risks associated with believing your own rhetoric. This was an example of a left-handed anomaly. Nate was left-handed and had skewed his body so that it became possible for him to write on the placemat on the table. To Keren, Nate was rejecting two people by showing them his back. The appearance was out of step or incongruent with the cohesive group attitude. There was a clash between what was ‘apparent’ and what was ‘evident’. My journal notes how I was able to incorporate this peripheral observation into my theoretical framework.

> *Perhaps my study of paradox has led to an increase in my awareness of evidence in science and thus increased understanding by the students themselves.*

Kendo - the Way of the Sword

I began my study by interpreting everything I read and accumulated knowledge; and in the end I interpret everything I read or observe in the light of the understanding I have acquired in my study. Dhyana Buddhism contains a number of useful concepts that have become part of my own rhetoric. My understanding of Buddhism has not occurred through any rigorous study, but rather through my engagement in martial arts training. Kendo, the way of the sword, practiced by many people throughout the world was originally based on the Japanese feudal art of swordsmanship. Japanese children practice Kendo as part of an educational curriculum from secondary school to university however nowadays many Japanese children prefer soccer, basketball and baseball.

According to Sasamori and Warner (1964)

> The student participating in kendo has the unique opportunity of studying firsthand an activity that has followed the continuous growth of his country from the historical past to the present. Followers of the sport find that it is not only a way of preparing for life during youth but also a code that can be carried on throughout all of life. (Sasamori & Warner, 1964)

Kendoka, those people who practice Kendo, attempt to reach *satori* or enlightenment following a principle which would suggest *satori* is not gained through the study of texts or other verbal explanations but rather through direct experience. For *Kendoka* direct experience is through interaction with ones masters or by meditation. The Japanese phrase '*satori kyōge betsuden* translates as 'enlightenment is not reached by way of written doctrinal exegesis'.

Kendo also encourages kendoka like me to continuously search for *fūryū*, meaning sophistication The Zen ideal, *fūryū monji* translates directly as 'not standing on words or letters'.

Although in Kendo there is a great deal of conversation with masters together with the most severe physical training, the emergence of understanding is somehow disembodied and diaphanous. When Feyerabend (1995) wrote, "… I also try to emphasize the essential ambiguity of all concepts, images, and notions that presuppose change. Without ambiguity, no change, ever" (p. 179), he illuminates the teaching style of my Kendo masters that has become embedded in my own science and Kendo teaching practices.

When the Education Department finally permitted me to take study leave after a year of argumentation and bureaucratic red-tape, that ended when the Commissioner for Review castigated them for their belligerence and ordered the immediate granting of my application, I spent my time at the University of Tasmania in Launceston either in the Library or in the cafeteria.

My very first coffee on my very first day found me sitting at a table by myself in a sea of very young and unfamiliar faces. I felt like a fraud. Shame-faced, I stared down at the table to avoid eye contact with those around me and noticed the following graffiti: “Steve is a fucked-up zombie”. Did the author know I was going to sit here? I composed the following poem in response:

> Loneliness
> Wandering in a sea of knowledge,
> No place to berth.
> What appears as scholarship,
> Is barely short of mirth.
>
> The faces of the dullards,
> Keep careening in on me,
> But pass me by with no concern,
> They do not come to see.
>
> They attempt to make what little sense,
> They should or could or might,
> Ending but bereft of life,
> For what they didn’t fight.
>
> The scholarship, it tracks us down.
> We need not go in search.
> It will find us regardless,
> Of our stature caused by birth.
>
> Our minds always are engaging,
> In the grandiose and brash.
> Some seem to always find it,
> With their bucket loads of cash.
>
> Yet look not far behind,
> In the shadows in the dark.
> You’ll bash your head
> And drop down dead
> Before you make your mark.

It was almost a year to the day since I’d listened to Professor Tom Barone talk about the case of Billy Charles Barnett and the response of Walter Lane to Billy’s story. Walter Lane’s poem is worth sharing here. Both poems, mine above and Walter Lane's below, I share along with a word of caution from Anne McCrary Sullivan. McCrary Sullivan claims,

> Many in the academic community, not having been taught to read aesthetic forms, reject them as representations of knowledge. If, however, we are to become literate in a wider range of the forms in which knowledge may be encoded, we must give attention to these forms. We must stare at them, ponder them, arrive at an understanding not only of what the forms contain, but also of how form informs."(McCrary Sullivan, 2000)

Walter Lane sent the following short letter to Barone in response to Barone's Billy Charles article I reproduce it here with permission.

> Sir,
>
> I read your case study in a discarded Kappan with interest. As a former participant in the "cash economy", I am fascinated by the dearth of scholarly work along the line of your case study. Most scholars miss the substance of the Appalachian economy.
>
> There are many "Billy Charles's" in the hills and byways, off from the mass society's notice.
>
> I would like to encourage you to pursue further work along this line. Thanks for developing for a mainstream audience some of the substance of another lifestyle.
>
> Walter Lane

Walter sent his poem, *Attitude Adjustment*, published in The Journal of Kentucky Studies in 1987, along with his letter.

Attitude Adjustment
By Walter Lane

I am no cloud watcher
nor school trained radical
I practice my writing
like a cannibal sharpening his knife
waiting for a missionary

I can still sit on the creek bank
where mother used to fish for our supper
people tell me
I can no longer freeload on nature:
Society has taken away the divine rights of fishermen
leaving behind Clorox jugs, food stamps, and other trash.

I don’t want to recall grandpa tilling his corn
I want to fill out a job application satisfactorily.
I don’t want to recall Thanksgiving with the dressing
I want a road map to supper.

The radio preaches me sermons on the necessities of
nuclear defense
personal computers

Yet, my mileage is measured in footsteps
An apprentice to a slave has greater job security.

The census takers shunned me.
I don’t fit into a Sunday suit
or their Washington formulas.
I just meander. Sometimes I wish I saw a distant star
or just once could lust after my cousin’s new Oldsmobile
Although I think my wife could be happy
If I came home with some electricity in my pocket.
I tell her light makes too much noise at night.

My private sermons are composed on the creek bank,
where I wear the used costumes of the rich:
(blue jeans are saved for town visits).
I know what a little lead in the water does.
(Like Socra[t]ies (sic) I drink my share)

My first bomb blew up in my bloody face.
The trial and error method is hard on an amateur terrorist.

I think I will develop immunity to a short fuse
by writing crazy letters to the editor:
“Take away the Clorox jugs.
Bring back the fish.”

(or else)

I was able to spend my hard-fought for study leave writing.

Whilst waiting for my wife's grandmother outside the Crown Casino in Melbourne's Southbank, I noticed a brass plaque, fixed to a wall, which read, "This area *may* be under video-surveillance." This plaque's purpose was to force a behaviour adjustment from those who read the sign.

Foucault (Danaher, Schirato, & Webb, 2000, p. 53) called this process of forced behavioural adjustment 'Panopticism' derived from Bentham's model of the panopticon.

Bentham described a tower in the centre of a prison that could see all prisoners and all cells. The prisoners, unlike the prison guards, are unable to know if the guards were observing them. Bentham's belief was that the prisoners would modify their behaviour because of their uncertainty as to whether the guards observed them. I believe the study of paradoxes can enhance the ability of students to hold abstract ideas in their heads. As I stood transfixed by the brass plaque I thought that it was highly probable that at that specific time, a security officer employed by Crown Casino wasn't observing me. The plaque fixers were operating on the assumption that the plaque had the capacity to reduce their own need to maintain expensive, constant surveillance. Paradoxically the plaque gave me added confidence that I wasn't under surveillance. They may as well have fixed a plaque to the wall that read, 'you're probably not currently under surveillance,' which would convince me but not those convinced by the first sign. Perhaps the sign should have read, 'This area *may* be under video-surveillance.

A quote from Foucault describes entirely the transformation I have perceived in myself during preparation of this thesis,

> …a historical investigation into the events that have led us to constitute ourselves [myself] and to recognise ourselves [myself] as subjects of what we are doing, thinking, saying… (From Foucault, 1997, Ethics: Essential Works of Foucault 1954-1984 by Paul Rabinow)

> …thought and [self] criticism, then, enable us to problematise – and, potentially transform – our subjectivity (op. cit.)

There are many ways to relate my students' study of science but eventually all my science students must begin to sense the flawed nature of how the average person constitutes a view of science. It is only an illusion.

Chapter 14 – The Illusion of Meaning and the Preternatural Language of Evidentiary Logic

> …the world just is not constructed on a common-sensical basis. (Wolpert, 1992)

Lewis Wolpert (1992) claims that science thinking is anything but, 'normal' in his book, *The Unnatural Nature of Science*.

Wolpert would suggest that the unnatural nature of science is capable of explaining the scientific illiteracy of the average person.

> This means that 'natural' thinking — ordinary, day-to-day common sense — will never give an understanding about the nature of science. Scientific ideas are, with rare exceptions, counter-intuitive: they cannot be acquired by simple inspection of phenomena and are often outside everyday experience… doing science requires a conscious awareness of the pitfalls of 'natural' thinking. For common sense is prone to error when applied to problems requiring rigorous and quantitative thinking; lay theories are highly unreliable (Wolpert, 1992, pp. xi-xii).

Charles Sanders Peirce, the founding father of American Pragmatism, called himself, "a critical common-sensist and fallibilist" (Wiener, 1966 Editor's note) to recognise the short-comings of common sense alone as a medium to construe nature. An inquiry may begin with a proposition of some sort but the proposition alone is not enough to stimulate an individual to, "struggle after belief." According to Peirce there must be "real and living doubt" (Wiener, 1966, p. 100). For Peirce (1878), the propositions of scientists are believed (accepted as true, real or genuine) by examining empirical evidence, "For objectivity is relevant to all statement which purports to make a claim, to rest on argument, to appeal to evidence" (Peirce, 1878; Wiener, 1966).

Peirce's fallibility doctrine has its modern corollary in Popper's falsification criterion. Peirce would claim that belief being the, "practical holding for true" whilst maintaining the possibility of beliefs being mistaken whilst Popper acknowledges the need for a proposition's capacity to be falsified as the critical criterion or demarcator of scientific propositions as opposed to those classified as meta-physical; the things that we can know.

Peirce illustrates his fallibility doctrine by pointing out the logical, “Insolubilia”, a term used prior to the fourteenth century to describe paradoxes. John Buridan (ca1300-1360) used the term “sophismata” such as the example of the liar sentence. (Thompson, 1949)

The proposition that, ‘This proposition is false’ is infallible and therefore, according to Peirce, is the means of its corruption.

The tag that Peirce grants to infallible beliefs, “Attribute of Godhead”, is a denial of the very possibility of any scientific claim being infallible.

Popper takes a similar view with the added acknowledgement that, although it is not possible for science to claim ownership of the logical truth of scientific propositions through inductive reasoning, it is nevertheless feasible that we know the empirical truth.

Peirce’s concession that reality is made and not discovered by scientists presented him with an unresolved difficulty that the common sense view of observable facts must in the end yield to arguments based on appeals to facts about observations that are intuitively unacceptable to many. Peirce puts it this way,

> And indeed there is a striking self-contradictoriness in the effort to persuade others by argument that communication, and hence argument, is impossible; in appeal to the facts about observation in order to deny that commonly observable facts exist; in arguing from the hard realities of the history of science to the conclusion that reality is not discovered but made by the scientist (Peirce, 1878; Wiener, 1966).

Manly Thompson (1949), was able to utilise Peirce’s semiotic to persuade his readers that the logical paradoxes such as the Liar Paradox are sophistic and through analysis of meanings of propositions, can be eliminated. Kurt Grelling’s Heterological Paradox, previously mentioned, is analysed and dealt with in a similar way by Thompson. If the proposition leads to a contradiction, then the proposition is ill-conceived because the Law of contradiction precludes contradiction. The Law of the Excluded Middle maintains that a proposition must be either true or false.

Empirical Evidence

When dealing with empirical science and the evidence pertaining to justifications of theory, students find difficulties arise because they can't resolve the contradictions evident in their observations by logical means without practice. Students can practice when studying paradoxes.

Unlike the field of logic it is possible for students to misinterpret empirical observations or perform inadequate experimental procedures, which fail to elucidate phenomena.

Logic is certain through the tautologous use of language (Cf. Quine, 1966; Wittgenstein, 2004). Whereas science is uncertain by its very nature; a nature that Wolpert sees as unnatural.

Scheffler (1967) quotes Otto Neurath's *Foundations of the Social Sciences* (1944, pp 13) to illustrate this re-defined dilemma rather than paradoxical situation,

> A social scientist who, after careful analysis, rejects certain reports and hypotheses, reaches a state, finally, in which he has to face comprehensive sets of statement which compete with other comprehensive sets of statements. All these sets may be composed of statements which seem to him plausible and acceptable. There is no place for an empiricist question: Which is the "true" set? But only whether the social scientist has sufficient time and energy to try more than one set or to decide that he, in regard to his lack of time and energy—and this is the important point—should work with one of these comprehensive sets only (p. 98).

My science students face this same dilemma, when it occurs to them. They too have sets of statements which compete with other sets of statements, each set containing its own persistent and unreconciled inconsistencies. Time and the energy to decide which set should receive their acknowledgment are the limiting factors.

Quine's (1966) "truth by linguistic convention" begs the question when Quine writes,

> A word may, through historical or other accidents, evoke a train of ideas bearing no relevance to the truth or falsehood of its context; in point of meaning, however, as distinct from connotation, a word may be said to be determined to whatever extent the truth or falsehood of its contexts is determined (p. 82).

I can say the same of concepts in science. Logical people, either students or scientists and teachers accept the principle of non-contradiction however, many students also accept logical contradictions as true (Cf. Lévy-Bruhl Doctrine) and thereby implicate the teacher's need for a stratagem for 'encouraging' their pupils when the time and energy required would normally be considered unavailable.

I encourage teachers, who may be initially unwilling, to recognise the need to avoid logical argument to convince a student to jettison their pre-logical and contradictory conceptions. We must take the position to either accept that the student is genuine in their own recognition of acceptance of their evident contradiction or alternatively that the conflict exists only in the teacher's understood meaning of the contradictory student propositions. Cognitive conflict research (Cf. Kang et al., 2004; Laburu & Niaz, 2002; J. Sandoval, 1995; Watson, 2002) would indicate some opposition to blind acceptance of the role of internal student conflict with failure of recognition of discrepant events the critical issue.

I point out that contradictions between student conceptions and discrepant observations, whilst recognised by their teachers, may not gain similar recognition by our students. Could a failure to recognise contradiction be due to the pre-logical state of the student or alternative meaning assignment or simply lack of time? High school Science students are inconsistent in their application of logical principles. I believe, as a consequence, teachers and students fail to assign equivalent meaning to the scientific propositions there are examining.

Quine (op. cit.) points out, “Deductively irresoluble disagreement as to a logical truth is evidence of deviation in usage (or meanings) of words” (Quine, 1966, p. 105).

Imagine the consequence for science teachers, if as Quine (1966) puts it, “Suppose someone puts forward and uses a consistent logic the principles of which are contrary to our own” (Quine, 1966, pp. 101-102). It is plausible that students chose to accept contradictions rather than the propositions of teachers because they simply fail to recognise the contradiction exists due to their lack of experience in logical analysis. The case of The Paradox of the Ravens is useful to consider because it shows practising scientists and science teachers such as me accept hidden assumptions and ambiguities.

Teachers may well decide to reject the evidence of a non-black non-raven for the generalisation that, ‘All ravens are black’ but these same teachers will accept the equivalence principle upon which they based their evidentiary logic. When this happens the teacher is accepting a contradiction which is prohibited by the Law of contradiction. Perhaps Quine’s interpretation of Carnap (below) offers a way out of this labyrinth.

> One conspicuous consequence of Carnap’s belief in this dichotomy [analytic and synthetic truths] may be seen in his attitude toward philosophical issues as to what there is. It is only by assuming the cleavage between analytic and synthetic truths that he is able to declare the problem of universals to be a matter not of theory but of linguistic decision. Now I am as impressed as anyone with the vastness of what language contributes to science and to one’s whole view of the world; and in particular I grant that one’s hypothesis as to what there is, e.g., as to there being universals, is at bottom just as arbitrary or pragmatic a matter as one’s adoption of a new brand of set theory or even a new system of bookkeeping.

Carnap in turn recognizes that such decisions, however conventional, “will nevertheless usually be influenced by theoretical knowledge.” Quine continues,

> But what impresses me more than it does Carnap is how well this whole attitude is suited also to the theoretical hypotheses of natural science itself, and how little basis there is for a distinction. The lore of our fathers is a fabric of sentences. In our hands it develops and changes, through more or less arbitrary and deliberate revisions and additions of our own, more or less directly occasioned by the continuing stimulation of our sense organs. It is a pale gray lore, black with fact and white with convention. But I have found no substantial reasons for concluding that there are any quite black threads in it, or any white ones. (Quine, 1966, p. 125)

The claim that, there are physical objects, classes or numbers are ontological statements. The claims that there are black swans or black ravens are empirical statements of existence. Quine believes that the connection between ontological and empirical statements is a continuum and no clear difference exists; those represented above being outlying statements. Besides ontological statements and empirical statements Quine also declares some statements meaningless. Carnap's statement, 'This stone is thinking about Vienna' would be an example of Quine's meaningless statements and perhaps, 'All ravens are black' is meaningless. Scheffler believes that Hempel based The Paradox of the Ravens on an illusion that is much too difficult to surrender. "Hempel suggested that the paradoxes are psychological illusions resting, in every case, on mistaken conceptions which need to be given up." (Scheffler, 1963, p. 283) Scheffler goes on to say,

> For consider Hempel's own explanations of the paradoxes. It is true that he traces the intuitive inequalities to a certain view which is held in fact, though mistaken, and to a prevalent intrusion of extra information, which is nonetheless improper. But his explanatory claim rests on the assertion that, when the mistaken view is recognised as such and given up, and when the intrusion in question is acknowledged as illegitimate and abandoned, the paradoxes no longer arise, for the intuitive inequalities vanish (Scheffler, 1963, p. 283).

My students demonstrate how a mistaken view when given up can lead to the abandonment of an apparent paradox. This occurred when my students investigated the paradoxical Mpemba Effect, which I discussed in Chapter 3.

When does an hypothesis become a generalisation? Observation of a number of black ravens does lead to the hypothesis, rather the question, 'Are all ravens black?' Observing a number of insoluble carbonates does lead to my students concluding that, 'All carbonates are insoluble'. Both hypotheses are testable and falsifiable, justifying their status as scientific claims, but neither is true.

A generalisation represents the likelihood of its claim being true, if I were to see a raven it is, 'likely' to be black. I base the generalisation upon the inductive reasoning of Hume: non-demonstrative inference.

Science is immutable yet never ceases to change. There is no guarantee of an outcome based upon a generalisation. Evidence does not lead to absolute positive affirmation, what I'd like to call proof, of a particular generalisation. On the other hand a disconfirming observation has the potential to disprove a generalisation.

At one time I thought that disconfirming evidence refuting a generalisation must mean that generalisations cannot possess logical opposites because if it were so then if a logical opposite exists it would be possible to disprove a logical opposite and thus *eo ipso* prove the generalisation. However, finding a single black raven capable of refuting the counter-claim that, 'All ravens are non-black' does not imply finding a single black raven constitutes proof that, 'All ravens are black'; the raven found represents only a very small increase in the probability that the statement, 'All ravens are black' is true.

'All ravens are black' is a scientific generalisation that I cannot prove however; I can disprove these kinds of existential claims.

Determining that, 'All ravens are non-black' is false with one black raven and thus ipso facto proving, 'All ravens are black' to be flawed logic shows that in order to conclude anything about the nature of ravens I must examine ravens and not non-ravens.

It would seem that the statement, 'Falsifying the negation of a statement is proof of a statement' is intuitively implausible and leads individuals to the plausible, yet false, conclusion that true opposites cannot exist. (Cf. Leo J. Brouwer – intuitionism)

Scientific Language – linguistic entanglement

The view that is expressed by the role that language plays in the development of scientific ideas and young scientific minds is expressed by Quine, “The notion of reality independent of language is carried over by the scientist from his earliest impressions, but the facile reification of linguistic features is avoided or minimized” (Quine, 1966, p. 220). Quine asks the question,

> But how is it possible for scientists to be thus critical and discriminating about their reifications? If all discourse is mere response to surface irritation, then by what evidence may one man’s projection of a world be said to be sounder than another’s? If, as suggested earlier, the terms ‘reality’ and evidence owe their intelligibility to their applications in archaic common sense, why may we not then brush aside the presumptions of science?

Quine answers his own question with the reply that, “The scientist is indistinguishable from the common man in his sense of evidence, except that the scientist is more careful” (Scheffler, 1963, p. 220). This care, referred to by Scheffler, which I must take, to explicate science for my students, is in regard to the insulation required to separate the average person’s view from the scientist’s view.

The response of Scheffler is quite common; there is a, ‘need’ almost to elevate the scientist above the delusion of logic.

Mathematics as opposed to logic can illustrate this point well if we look at the response of the logician and the student to mathematical fallacy. When I asked a 15 year old to examine a proof of a = b, therefore 1 = 2; Steve simply stated, “But 1 does not equal 2.” Agostini (1980, p. 97) says that, “If we reach a contradiction on the solution of a mathematical problem…then one of the starting premises is false.”

The mathematician or logician accepts, within the field of mathematics, that a mathematical paradox, according to Agostini (op. cit.), “involves a succession of steps in reasoning that contradict common sense and are therefore amazing or amusing.” Although amused by the mathematical paradox the resolution of the paradox I handle by pointing to my student’s false premise and barking, “See here, here’s your error.”

It may well be reasonable to use my student’s method of resolution of mathematical paradoxes in our dealings with logical and semantic paradoxes. The serious difficulties were called *Aporiai* by the Greeks and the reference of Aristotle to, ‘dichotomy’ when mentioning Zeno’s paradoxes such as Achilles and the Tortoise establishes my contention that in analysis of paradox we have alternative paths; path ‘A’ leads to establishment of the paradoxical nature of the logic and path ‘B’ leads to outright rejection of the paradox as delusional.

Kurt Grelling’s Heterological Paradox devised in 1908 can illustrate mans’ capacity to invent statements that, although they are used to define the concept of paradox, are fabrications utilising the semantic structure of language to generate the paradox. Grelling divided adjectives into those which are self-descriptive, the so-called autological adjectives and those which are not self-descriptive, the heterological adjectives. Grelling’s Paradox emerges when we ask the question is the word ‘heterological’ heterological or autological?

I, like Rudolph Carnap, believe that “all concepts are ambiguous” and the concepts heterological and autological are no different. The concepts heterological and autological are consistent when used in reference to other adjectives. Logical, semantic or linguistic entanglement is a consequence of self-reference. My students offer examples of entanglement.

Defining concepts such as heat and density by direct reference to the concepts is one of the entanglement or self-reference difficulties confronting high school students who are asked to define heat or density. It requires little effort, on the part of the teacher, to point out to students the need to define concepts by referring, not to the concepts directly but by the use of extant student language.

Linguistic and semantic paradoxes seem very difficult to expunge in the same manor yet they do offer examples for my students to study in order to recognise the frailty of self-reference.

If one assumes then, as I indicated in my journal, that all paradoxes are *"fallacious sophistry"* then Hempel asserts absurdly that all non-black non-ravens are evidence for, 'All ravens are black' or my present evidentiary logic is flawed.

If statement S, that we assert, is an assertion of fact then we can declare that S is true or false. If however our assumption that 'S is fact' is false then the declarative statement of the truth or falsity of S is mute. Consider the statement 'All unicorns possess one horn', how many horns do they have? The false statement L; Launceston is in Brazil is still a statement because it can be declared true or false.

Although logic as a science goes back to Aristotle in 4th Century B.C., mathematical logic developed in the 19th Century very much requires strict and meticulous reasoning to avoid ambiguity and maintain simplicity and yet, again, Carnap would claim that, 'All concepts are ambiguous'. How then do I reconcile the ambiguous nature of concepts with the need of mathematical logic to avoid ambiguity?

From where does the ambiguity emerge? How do I avoid ambiguity in mathematics and how can I avoid it in linguistic logic and my science teaching? In mathematics, the truth of the axioms I assume and when, in the case of set theory, Russell stumbled upon ambiguity, the axioms were altered, I previously indicated ZF Set Theory, to eliminate Russell's Set Paradox. The word 'always' provides ambiguity in everyday language but not in mathematical logic; the ability to always state a 'number larger by one' is unambiguous.

When 'always' is used to describe a student's capacity to be punctual, the word logically requires the student to: Without exception arrive to class on time.

Needless to say when report writing is undertaken I end up quarrelling with many colleagues who assume a divergent meaning of the word ‘always’.

The same too, I can say for students in the process of examining scientific claims written in generalised terms. ‘Carbonates are always insoluble’ is interpreted broadly by the student and narrowly by their teacher because the meaning of the term ‘always’ has been hammered home by years of exposure to the claims by parents and siblings; “You always leave your room in a complete mess.”, “You always mess with my things”. The direct teaching of the narrower definition seems to be of great significance in my science classroom.

Returning to the example of student punctuality reporting, I am chastised by colleagues for being too harsh with my interpretation of the punctuality criterion on reports sent home mid-year. It has been my habit to record, student lateness both with attendance and homework assignments by recording in my attendance register the number of minutes late to class and the number of days late with assignments. When the time to register punctuality arrives, a quick scan reveals if a student has been ‘always’ punctual or not. My colleagues have told me that my adherence to a strict definition of ‘always’ is preventing some students from being recognised with a certificate for their application to studies. I have been told by many concerned colleagues that ‘always’ means, in reference to punctuality, ‘mostly’

When asked to justify why the word ‘mostly’ is not substituted for the word ‘always’ in reports colleagues respond by implying that the term always has a tacit dimension that is recognised by all staff other than myself.

Although it dumbfounds me to this day why the school administration in question is insistent upon a liberal interpretation of ‘always’ it illustrates perhaps why students have such difficulty in assessing generalised statements when common sense dictates to logic and the majority of the students’ teachers think the same way.

The heuristic value of concepts as a tool to draw students inexorably toward increasing sophistication evidenced when students can derive a consequence, as yet unseen, from a generalised statement students made clear to me when they attempt to explain phenomena. I have used the reaction between lead nitrate and potassium iodide as a means to illuminate the particle nature of matter and the kinetic theory of heat. Crystals of each compound placed 15cm apart in a basin of still water eventually produce a yellow band of solid lead iodide, affirming the doctrine of matter as minute moving particles. In the words of Quine (1966),

> In its manifest content the molecular doctrine bears directly on unobservable reality, affirming a structure of minute swarming particles. On the other hand any defense of it has to do rather with its indirect bearing on observable reality. The doctrine has this indirect bearing by being the core of an integrated physical theory which implies truths about expansion, conduction, and so on. The benefits of which the molecular doctrine, as core, brings to the physics of these latter observable phenomena (p. 235).

When my students are able to go beyond the observed phenomena and use particle theory to make predictions about future observations they have grasped the essence of the theory in question. In the case of particle theory, its conceptual simplicity allows the student easy entry into the scientific enterprise of making knowledge claims based upon their theories. If the water basin is heated then the particles will move more rapidly speeding the process of diffusion and allowing the reaction between lead nitrate and potassium iodide to occur sooner. Framed as a question in the form; *If* the water basin is heated *then*…, students are able to utilise the theoretical framework, derived from their examination of paradoxes, to suggest a plausible outcome. If, on the other hand I leave students to pose their own questions to test the predictive power of the theory using ‘If…Then’ logic form, only limited numbers of questions arise. Students misconstrue the success of the theoretical framework in making meaningful predictions of behaviour of chemical systems such as just illustrated as evidence of the truthfulness of the theoretical model. Quine (op. cit.) warns us to consider,

> This reflection strengthens a natural suspicion: That the benefits conferred by the molecular doctrine give the physicists good reason to prize it but afford no evidence of its truth. Though the doctrine succeeds to perfection in its indirect bearing on observable reality, the question of its truth has to do rather with its direct claim on unobservable reality. Might the molecular doctrine not be ever so useful in organizing and extending our knowledge of the behaviour of observable things and yet be factually false? (p. 235)

Quine (1966, p. 237) refers to what I would call 'slack' in the empirical nature of science, describing science as being "empirically under-determined", it is this aspect of the nature of science and evidence that is rendered unconcealed through the study of paradox. "If we have evidence for the existence of the bodies of common sense, we have it only in the way in which we may be said to have evidence for the existence of molecules." Quine indicates the claims of the scientist and the student differ only in the degree of sophistication, a term I have regularly used in this thesis and a term that philosophers of science regularly use.

Within Science teaching there exists a 'central paradox of science teaching'; the necessary integration of the fundamental scientific principle of simplicity (Cf. Ockham's Razor) with the attainment, by our students of scientific sophistication.

The adjective sophistication has as its root in the Latin *sophisticus* meaning sophistic. I have chosen to always use unsophisticated to mean 'inexperienced' or 'uncultured in the ways of science' yet it is notably ironic that one could employ 'sophisticate' to mean an individual learned in the art of fallacious reasoning for the purpose of deception.

> The positing of either sort of body is good science insofar merely as it helps us formulate our laws — laws whose ultimate vindication lies in anticipation of sense data of the future. The positing of molecules differs from the positing of the bodies of common sense mainly in degree of sophistication. In whatever sense the molecules in my desk are unreal and a figment of the imagination of the scientist,

> in that sense the desk itself is unreal and a figment of the imagination of the race (Quine, 1966, p. 237).

The “sophistication” of Quine contains an element of sophistry, here Quine bangs your head on a desk and asks you to deny the reality of molecules, whilst Lewis Wolpert (1992) is adamant, “…that ‘natural’ thinking — ordinary, day-to-day common sense — will never give an understanding about the nature of science.” (pp. xi-xii)

It is the view of Quine, among others, that the average person lacks the cultural understanding of the scientific way and therefore cultural exposure and experience would lead to the desired sophistication. I hold the view that experience, although important, and enculturation essential; what presents as crucial is acknowledgement that the natural thinking referred to by Wolpert is better represented as naïve, inexperienced scientific thinking and that the average person’s capacity for comprehension of scientific concepts is dependent on the teacher’s capacity to use language capable of reaching out to his students. Perhaps studying paradoxes does exactly this.

Conclusion

I’m currently sitting on a hard wooden chair in a monk’s cell in the St Yves, in the cathedral town of Chartres, Northern France. It’s not a particularly nice day. It is stoic. Overcast. The only creature that seems to find the day joyous is the swallows that slice the sky into a thousand coloured ribbons. Paul Kelly is playing on my IPod compelling me to think about returning home to Australia, across the painted ocean. I’ve traversed a great labyrinth and have been away for a very, very long time. A beautiful and good natured woman waits for me. Theseus forgot to unfurl his white sail and the consequences were dire. Like Theseus, I value rational thinking, in my work with my Science students. Unlike Theseus, I recognise the value of irrational thought when it comes to matters of the heart. I will not reject my Ariadne. I have no idea why I desire to share the remainder of my life with this remarkable woman and I don’t intend to search for one but if I was to hazard a guess I’d say that she has been able to show me the way out of my labyrinth.

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